

**CANNOLI FRAMING**  
THE TURNSTIJL HOUSES AND CONFIGURE-TO-ORDER

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Academic Faculty

By

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Everything made for the greatest number is ugly, dreadful, misleading, and fraudulent. That's what I think is so serious. They want anything at all as long as it looks like something they know.

Jean Prouve

Charles had clearly learned that if you were designing for mass production, you had to discover how to make the tooling - not just the end product - yourself.

Eames Demetrios

Shall I call that wise or foolish, now; if it be really wise it has a foolish look to it; yet, if it be really foolish then has it a sort of wiseish look to it.

Herman Melville

Idealism is a contemporary form of hope. The future is the projection of the past conditioned by the present.

Georges Braque

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## SUMMARY

Beginning with the study of type, house typologies, manufactured houses, and structure classification, this thesis proposes the design and fabrication of a hybrid structural insulated panel (SIP) and laminated-stud (Lam) framing system developed using contemporary three-dimensional modeling techniques and digital production methodology.

Included within are prototypes, assembly diagrams, and structural tests of the proposed Cannoli Framing System (CFS) as well as three speculative Turnstijl houses whose systematic variation demonstrates the flexibility and scalability of the proposed system. In essence, this is the design of a framing typology capable of structural and formal variability to a degree that has previously been neither feasible nor affordable.

Please see <http://Turnstijl.com> for more information and ongoing developments.

## CHAPTER 1 | INTRODUCTION

This thesis presumes that integrating modeling tools and digital fabrication technology into architectural practice will transform how we build the detached house. Single-family houses come in all shapes and sizes, and in doing so imply variation as well in certain materials, methods, and lighter structures. Ultimately, houses are extensions, if not expressions, of those dwelling within, yet our attempts to provide appealing, affordable, manufactured houses repeatedly fall short of this ideal. Having typically prioritized standardization over variation, homebuilders have failed to harness the benefits of advancing technology and continue to stifle the uniqueness we so desire.

In response to such observations, and drawing upon meta-themes (i.e., *blending* and *transition*) present in contemporary design, this study proposes a hybrid SIP/Lam framing system and a corresponding family of houses. The development of the **Cannoli Framing System (CFS)** through three-dimensional and physical models culminates in the machining and testing of full-scale prototypes. Three demonstrations, branded the **Turnstijl Houses**, are generated using a phased process in which schema, structure, and system geometry may be personalized at conception.

This thesis pursues **variation** of type and explores the connection between type and production methodology. Additional questions are raised and addressed, such as how is a categorical notion like type defined, affected, and even “bred”?

**PART ONE – TYPE TO VARIATION**

## CHAPTER 2 | TYPE, PROPERTIES, AND SCHEMA

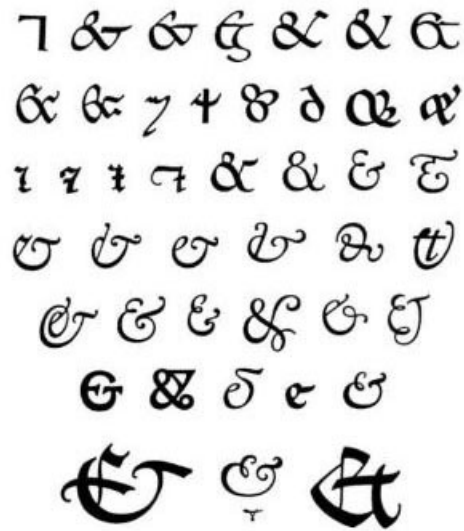


Figure 2.1 | Ampersand Variation - Frederic W. Goudy<sup>1</sup>

Webster's Dictionary suggests that distinguishing type depends on "the morphological, physiological, or ecological characters by which relationships between organisms may be recognized."<sup>2</sup> This is "taxonomic essentialism," and may be traced to Aristotle's hierarchy (genus, species, individual) from which an empirical resistance to classical idealism was derived.<sup>3</sup> This approach conveys the internal-external division involved, and suggests that type is discernable through the collection of properties. Specifically, the biological analog is inadequate, however, for architectural purposes because it assumes an a priori organic relationship between internal morphology and external form. Our architecture, unfortunately, does not naturally grow and must undergo an atomic transformation to go from idea to physical realization.

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<sup>1</sup> Goudy, Frederic. A Half-Century of Type Design and Typography. 1895-1945. New York: Typophiles, 1946, p. 239.

<sup>2</sup> "Type." Webster's Third New International Dictionary. 14 ed. 1961.

<sup>3</sup> DeLanda, Manuel. New Philosophy of Society. New York: Continuum, 2006, p. 26.

As a linguistic point of departure, we turn to American philosopher C.S. Peirce who contributed a crucial distinction between types of objects and tokens or instances.<sup>4</sup> Of this, William Mitchell explains that, “a token instantiates or is an instance of a type.” Nearby, he adds that tokens are “unique physical entities that we find located at a particular place at a particular time. Tokens may be of the same type by virtue of having something, for example, shape, in common.”<sup>5</sup> The significance of this is the separation of actual occurrence from category (i.e., types), and most importantly, that membership in the category depends on *shared properties*.

As our preliminary objective is to understand type more clearly in order to begin to conceive its variation, a closer look into its formation is required. William Mitchell’s characterization of the “basic empiricist assumption” offers us some insight into type’s initial formulation:<sup>6</sup>

*Type is an abstraction formed by dropping details which vary idiosyncratically from one exemplar to the next and retaining only the residue of commonality.*<sup>7</sup>

What Mitchell describes is a procedural distillation during which selection and omission of properties define type. The “abstraction” part is pertinent to our purposes later, but the phrase “residue of commonality” is vague and poses some immediate difficulties. Questions abound, such as how during the stripping away of variation does a linkage become apparent? Additionally, how is a definition stated or recorded, and in what way are comparisons made between types? These are all

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<sup>4</sup> Peirce, Charles S.. Collected Papers of Charles Sanders Peirce. Cambridge, MA: Harvard University Press, 1931-58.

<sup>5</sup> Mitchell, William. The Logic of Architecture. Cambridge: MIT Press, 1990, p. 98.

<sup>6</sup> Ibid, p. 98.

<sup>7</sup> Ibid, p. 94.

reasonable grievances; however, the notion that we define type through some kind of systematic reduction is misleading and must be addressed.

If we realize that by “residue of commonality” Mitchell is also referring to *shared properties*, things start to become clearer. In turn, we may recognize that the identification of common properties is actually a positive process and is not reductive. This is crucial because it reveals those properties *not* shared between instances as a source of variation. Supporting this assertion, a statement from E.H. Gombrich contests Mitchell’s suggestion that the varying details are simply “dropped” during the type recognition:

*The principle of sacrifice admits and indeed implies the existence of a multitude of values. What is sacrificed is acknowledged to be a value even though it has to yield to a value which commands priority.*<sup>8</sup>

Sir Gombrich’s phrase, “value which commands priority,” is meaningful because it clearly insinuates that an ordering of properties exists for type. In addition to type’s dependence on common properties, we now know that there is a structure to them. This raises the issue of a need to distinguish between essential and accidental (or non-essential) properties, to which the notion of the absolute essence is bound.

Within the discipline of architecture, two figures are commonly used to introduce the dialectic of essences: Marc Antoine Laugier and A.C. Quatremère de Quincy. The former is known for his deliberations on beauty, and his anecdote about the

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<sup>8</sup> Gombrich, E.H.. Norm and Form. London: Phaidon Press, 1966, p. 97.



prototypical “primitive hut,”<sup>9</sup> which for him was a universal architectural prototype.

The essence of a type, according to Laugier’s methodology, is revealed by distinguishing between those parts that are “introduced by necessity” and those “added by caprice.”<sup>10</sup>

The latter, Quatremère, saw a difference between a *model* that is “exactly” imitated, and a *type*, with an “elementary principle” that is “more or less vague” after which we “conceive works which do not resemble each other.”<sup>11</sup> Such thinking implies variation about a fixed point, and in both cases, the essence is understood as intrinsic to the nature of the token.

Immanuel Kant, takes different route, eschewing the notion of absolute essences and using the term “schemata” (singular: schema) to define the conditions for the existence of a type. Below, he prescriptively situates the verbal schema relative to its diagrammatic representation:

*In truth it is not images of objects but schemata  
which lie at the foundations of our pure and  
sensuous conceptions.*<sup>12</sup>

Rather than adopt Kant’s rigidity, we will opt for a looser interpretation where “schema” is used when referring to or stating the necessary conditions for a type’s existence and to verbal or diagrammatic representations of them. The principal difference between Kant’s relativist mode of operation and the absolutist approach, is as Mitchell tells us, “properties are of the same basic kind, and what we take to be of

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<sup>9</sup> Mallgrave, Harry Francis. Architectural Theory: An Anthology. Oxford: Blackwell, 2006, p. 143.

<sup>10</sup> Mitchell, William. The Logic of Architecture. Cambridge: MIT Press, 1990, p. 88.

<sup>11</sup> Quatremère de Quincy, A.C. “Type” In Dictionnaire historique d’architecture. Paris: Librairie d’Adrien le Clere et Cie., 1832, p. 629.

<sup>12</sup> Kant, Immanuel. The Critique of Pure Reason. Book II, Chapter 1, 1872, p. 182.

the essence of something depends on our interests of the moment or the quirks of vocabulary.”<sup>13</sup> This is a linguistic argument against essence, which suggests type is a function of what has been stated or defined outright. In this modality, a number of conditions can be specified for the existence of type, and the accidental vs. essential divide is not defined by nature, but is purely nominal. As the work presented here is involves organizational logic, topology, and is reliant on virtual means of representation, a relativist approach was favored over the absolute.

By now, if has been well enough established that type, regardless of modality, depends upon common properties, this is enough to begin speculating about how we may consciously create variation. With all the talk of essences, or rather schemata, how can we help but think of these as attractive targets for manipulation in the name of variation? If, in the relativist modality, the schema is the highest-level property of type, operations performed upon it (...or them) should presumably yield the most dramatic results. In particular, at issue is to what extent does type endure if non-schematic properties are manipulated, and what results when schemas are combined?

To set forth explicitly the Neo-Kantian convention used in this thesis, three elements are presented whenever defining type. These are the verbal schema, its associated diagram, and a quantitative property. It is emphasized that both the program and the schema are properties, however, only specific propositions are treated or referred to as schemata in this thesis (e.g. a house must have program generally). For the sake of clarity, what is most important, before moving on, is that we simply to arrive at a conceptual understanding of type as a *category*, i.e., a metaphysical construct based on the conjunction of shared properties, whether these logical, physiological,

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<sup>13</sup> Mitchell, William. The Logic of Architecture. Cambridge: MIT Press, 1990, p. 91.

morphological, or otherwise. In this way of thinking, type is categorical, may have some hierarchy of properties, is mind-dependent, and exists in abstraction.

### CHAPTER 3 | PROPERTIES, CAPACITIES AND VARIATION

Though useful for establishing a critical language, we should remain aware that typological thinking is top down. Philosopher Manuel DeLanda cautions us of the shortcomings of taxonomic methodologies and additive essences saying, they “will obviously not account for emergent properties since the latter, by definition, is that which goes beyond any simple addition of parts.”<sup>14</sup> This emphasizes for us that the relationship between type and its properties is not linear (i.e., type is not exactly the sum of its properties). In his most recent work, DeLanda introduces a new term into the fray stating that, “*capacities* do depend on a component’s properties, but cannot be reduced to them since they involve reference to the properties of other interacting entities.”<sup>15</sup>

This last quote is evidentiary of a theme, the connection of properties and capacities, first encountered during 2006 Uniformity & Variability symposium at Georgia Tech. There, the example of a knife was discussed and an argument made connecting the material’s properties to its capacity for sharpness. The key point being that it was the metal’s capacity to hold an edge, and not simply that it is metal or a knife that allows the variation. Elsewhere, and discussing a knife, DeLanda states, “what matters from the philosophical point of view is precisely that toughness or strength are emergent properties of a metallic material that result from the complex dynamical behavior of some of its components.”<sup>16</sup>

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<sup>14</sup> DeLanda, Manuel. “Emergent Properties” Retour à la page Symposium, 1992.

<sup>15</sup> DeLanda, Manuel New Philosophy of Society. 2006, p. 11.

<sup>16</sup> Manuel DeLanda, “Uniformity and Variability,” Netherlands Design Institute, Amsterdam, Holland, 1995.

Such thinking, considered in the context of our discussion of type, leads us to the epiphany that there may be more involved in variation than simply the manipulation of non-schematic properties or operation upon schema themselves. It is increasingly the case that advancing technology is playing a role in the conscious production of variation.

To describe the houses proposed by this work in DeLanda's terminology, one of their properties is that we make them on and by equipment that has a greater capacity for precision than has existed before. More specifically, this increase in capacity facilitates the affordable cutting of curves, something that previously required patterns, patternmakers, or some other sequence of elaborate steps and/or tools (e.g., French curves in drafting). In the case of the Exercise 3, this increase in capacity allows the articulation of the structural seams to such an extent that literally every piece of the house becomes unique. Although many of the pieces are self-similar, no two are actually identical - this is true at least for those located within doubly curved portions of the structure. This geometric variation is also, literally, mass customization, which again, is possible because how the houses are made is a property whose capacity for variation has increased.

More than a local revelation, this kind of causal explanation draws on *Assemblage Theory*, as reconstructed by DeLanda, where entities previously conceived to be heterogeneous nests of instances are now wholes. To quote DeLanda, "Entities ranging from atoms and molecules to biological organisms, species, and ecosystems may be usefully treated as assemblages, and therefore as entities that are products of historical processes."<sup>17</sup> This thinking, developed from fragments of Gilles Deleuze

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<sup>17</sup> DeLanda, Manuel. New Philosophy of Society. New York: Continuum, 2006, p. 11.

and Felix Guattari's work, speaks directly to the connection between production methodology and variation. A quote from their *A Thousand Plateaus* may help to clarify things further.

*Take the example of the saber, or of crucible steel. It implies the actualization of a first singularity, namely the melting of iron at high temperature; then a second singularity, the successive decarbonations; corresponding to these singularities are traits of expression [like hardness, softness, and finish]... We may speak of a machinic phylum, or technological lineage, wherever we find a constellation of singularities prolongable by certain operations, which converge, and make the operations converge upon one of several traits of expression.<sup>18</sup>*

In Deleuze's terminology *now*, digital production methodology relating to houses is a "singularity" of the assemblage. The houses are part of a "machinic phylum," and as such, all assume a specific technological lineage . . . one that is digital and whose trait of expression is *precision*. This precision is (bear with me now), a property of a singularity and is where the increased capacity for geometric variation comes from. This however, is also not the *only* such trait being expressed.

Architect Bill Massie identifies another when he states that "advances in electronics and computer processing found in CNC technology allow us to move from computer model/computer drawing to built form. This technology [...] eliminates the distance between virtual architectural hypotheses and the physical test of construction."<sup>19</sup>

Back with DeLanda, what is going on here is by virtue of proximity, we have naturally begun "tapping into morphogenetic capabilities in the process of producing."<sup>20</sup> This

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<sup>18</sup> Deleuze & Guattari. *A Thousand Plateaus*. New York: Continuum, 2001, p. 406.

<sup>19</sup> AD Vol 72 #5. Versioning. West Sussex: Wiley + Sons Ltd., 2002, p. 55.

<sup>20</sup> DeLanda, Manuel. *War in the Age of Intelligent Machines*. Cambridge: MIT Press, 1991, p. 19.

affirms Massie's thinking, and suggests that both material properties and software will play greater roles as the architect evolves to become part fabricator and part process engineer. It also causes us to consider the architect's facility with the new equipment in terms of capacities. Depending on one's view of the state of the profession, or rather, the new generation of practitioners themselves, this is cause for celebration or for alarm.

## CHAPTER 4 | HOUSE TYPOLOGY

The detached house, itself a typological category, contains familiar types like the ranch, the split-level, the duplex, the bi-level, and the shotgun shack. Nominal differences aside, many commonalities exist between these groupings such as material (wood), framing method (balloon/platform), structure class (shear panel), location (suburbia), and even cladding. We should not, however, just by default interpret these shared properties as prerequisites, for they are not all schemas for the type. In an effort to more accurately describe the types mentioned above, the most meaningful distinctions between them are found in the *organization* and *quantity* of program.



Figure 4.1 The Shotgun

### The Shotgun

Let us consider the example of the shotgun shack, a house typology tied to mill-towns and early twentieth-century industrialization. These houses are famous for one extremely simple detail - an occupant could conceivably stand on the front porch and fire a shotgun down the straight hallway through to the backyard. Whether the “shotgun” moniker came from the difficulties of policing the mill neighborhoods, or from workers returning home to catch their spouse’s suitor fleeing through the rear



door will not be resolved here. Whatever the case, these curious elongated houses possess the simplest of schemas: straight circulation.

Quantitatively, they also typically had either one or two bedrooms, an entry or common room, and a kitchen and a bath grouped in the back. Prior to air conditioning, the narrowness of the house had the practical advantage of aiding ventilation. Other factors, from the shape of a subdivided lot to the ease of extrusion of an orthogonal framing system, may account for the straight, single-loaded circulation of the shotgun. Each of these factors is circumstantial, but may be argued as having influenced its initial development. This vernacular structure illustrates the schema clearly, and again raises the issue of a hierarchy to the properties of type.

It is problematic to consider the schema against the backdrop of architectural history as traditionally the organization of space has been represented two-dimensionally. Because of this, schema has become irrevocably associated with plan, which seems to have precipitated a flattened, topological understanding of it. To use an example from the vocabulary of practice, when architects discuss “schematic design” or “schematic program,” they are referring to an abstracted version of the plan.

Such practical usage, though correct, also contributes to schema’s association, often confusion, with the plan-driven organization of space. In an attempt to avoid perpetuating this planar interpretation of it, the level-changing schema has been included in the Turnstijl houses (Exercise 2).

## Types Compared

Beyond the shotgun, the initial survey of house typology involved two other types, selected for their contrasting schemata. The split-level house, of course, has a level-changing schema, whereas the first level property of the duplex is its two-program schema. Figure 4.2 below illustrates the comparison between their quantitative properties and typical plans. Occupying the gray area, the duplex, at this scale, arguably still qualifies as a detached house because “single family” and “detached” are not synonymous. This would be harder to argue for a Triplex. For the sake of brevity, the anecdotal histories of the duplex and split-level are omitted, but may it suffice to say that the differences in their organizational logic is the primary schematic distinction we need to recognize. This means of representing type serves as the starting point for the inventory of sub-types in Exercise 2.

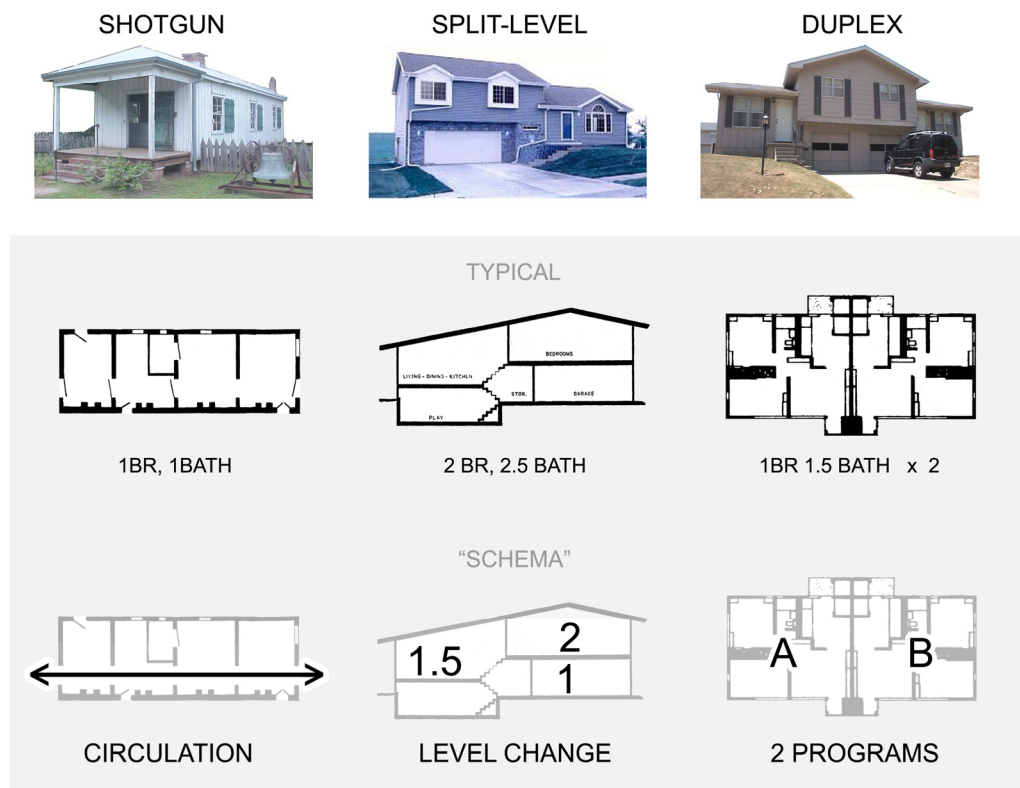


Figure 4.2 | Program Quantity & Schema - Aeck

## Framing

Dependent on the age of the three houses just mentioned, one of two basic framing typologies are usually encountered - either balloon or platform framing. Popularized during westward expansion according to Giedion, the balloon frame developed prior to the standardization of lumber dimensions, and before improvements in fire regulations required blocking.<sup>21</sup> As shown by the representations of each in Figure 4.3 below, the continuity of members relative to the intermediate floor is the most obvious difference. A more subtle difference between these two exists in how each is sheathed (not shown). The development of plywood hastened the obsolescence of the diagonal non-structural “board-sheathing” used in balloon framing.<sup>22</sup> By comparison, a 4’x8’ sheet of plywood performs the same task in the platform frame but *is structural*. The plywood’s advantage of rapid application eliminated the need to inset dimensional lumber as permanent lateral bracing having made this redundant. Today, workers affix diagonal studs temporarily to the bents before the sheathing is applied, and once the sheathing is complete, the workers remove the diagonal studs.

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<sup>21</sup> Monteyne, David: JAE “Framing the American Dream” 2004 p.24-31

<sup>22</sup> Ibid, p. 25.



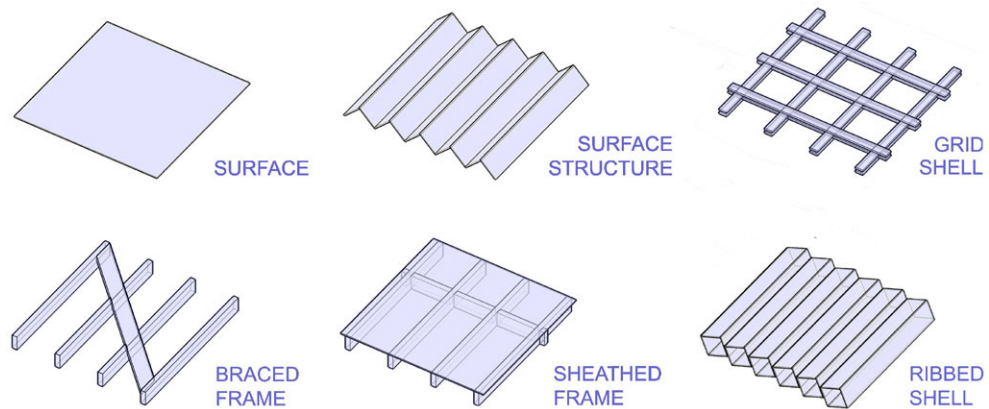


Figure 4.4 | Light Structure Classification - Aeck

These six images in Figure 4.4 illustrate some common classes of structure, most of which are either discussed or referred to within this thesis. This mode of representation occurs from this point forward when graphically representing structural class.

Figure 4.5 below represents a comparison of two framing typologies based on material, structure class, span, and system proliferation. In contrast with the wood platform framing system, the metal framing system has a greater span capacity, but a reduced capacity for subdividing space. Literally modeling each framing typology in detail served as a crash course in the assembly and proliferation of each. The inability to modify the radius of the Quonset's stamped sheet is a constraint tied to its production, and unlike the platform, does not lend itself to field modification. The typical effect of this constraint is that a second class of structure is used when to partitioning, or otherwise dividing the space within. A simple example of this occurs in Figure 4.5, but it may helpful to think of the office in an automotive garage or a supervisor's booth at a factory.

Such observations aid in the realization that classes of structure have radically different capacities based on *both* their material and tectonic properties.

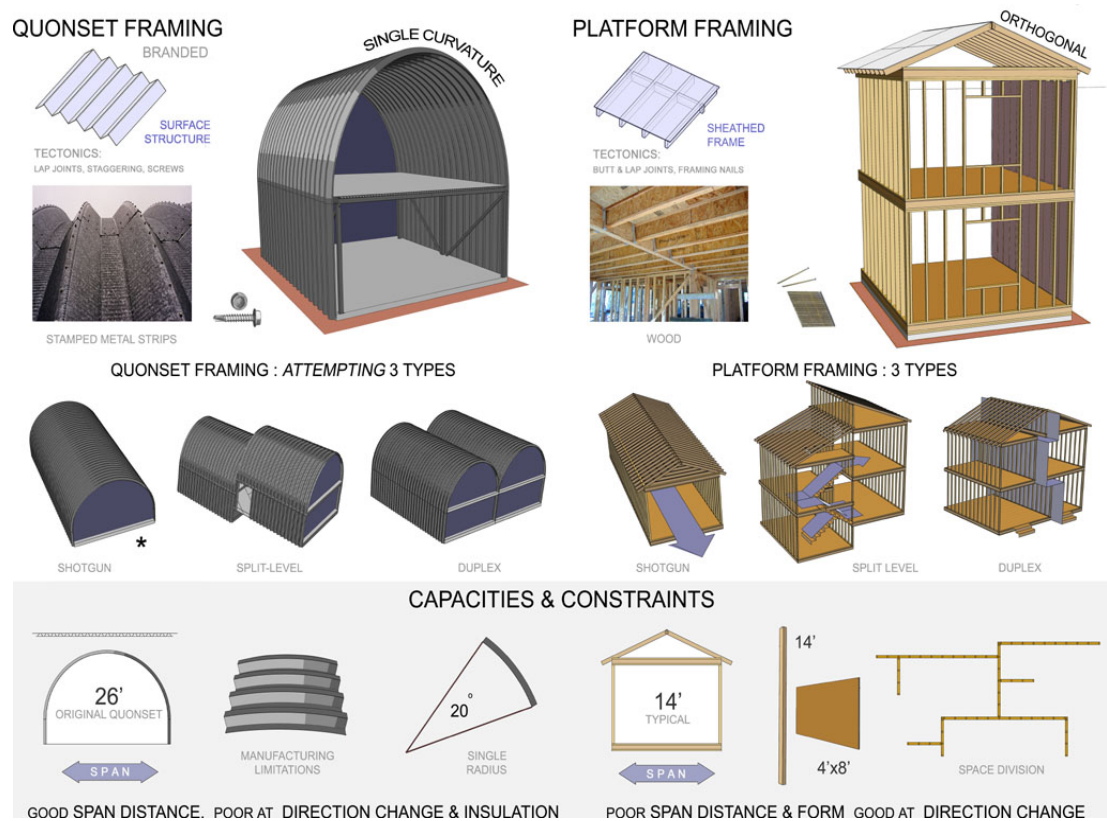


Figure 4.5 | Structure Class - Aeck

A further example of how a framing typology's tectonic capacity to order space influences type is shown in the center-right row of Figure 4.5. Here, the platform frame easily extrudes for the shotgun and slides past itself on both X- and Y-axes to create different size spaces and level change. Observing the metal system's comparative deficiency at both, it is not such a leap to infer its connection to the emergence of split-level houses. To attempt a similar level change using the balloon frame, a builder would have to create notches on both sides of a continuous

member. This technique is inferior because of its difficulty, but also because it causes weakness if the notches are local to one another.



Figure 4.6 | Wartime Framing Systems<sup>24</sup>

Figure 4.6 shows a familiar metal framing typology commonly associated with both World Wars. Engineered in Canada originally for the British government, the Nissen hut served as a model for the U.S. Military's "T-Rib Quonset." The principal advantages of the structure were that it could be assembled "in 1 day by 10 men," and "it came in 12 crates" and "required no special skills to erect."<sup>25</sup> In hopes of redistributing labor off site, the proposed system depends upon more pre-assembly where workers make tube-to-tube connections on site. The George A. Fuller Co. and Stran-Steel were the corporations that held the military contracts, yet to this day the name "Quonset" has endured and serves as a catchall for similar such systems.<sup>26</sup> The name "Quonset" refers to the location of the production facility at Quonset Point, Rhode Island that came to serve as a kind of ad hoc brand. Rather

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<sup>24</sup> Decker & Chiei. Quonset Hut: Metal Living for a Modern Age. New York: Princeton Architectural Press, 2005, p. 7.

<sup>25</sup> Ibid, p. 148.

<sup>26</sup> Ibid, p. 2.

than allow the branding to evolve naturally, the development of the branding for both system and product has been considered integral to the task.

There is a striking amount of variation in the design, application, and production methodology of the arched-metal structure during wartime. These structures served at many scales from barracks to blimp hangar. In a particularly divergent case, Frank Hobbs designed the all-wood “Pacific Hut” in response to metal shortages and to the tendency of metal Quonsets to corrode in tropical climates.<sup>27</sup> Of anyone, perhaps Hobbs would most readily agree that the metal house, as will be seen with Prouve, Fuller, and Strandlund, is something that only the military will ever really love.

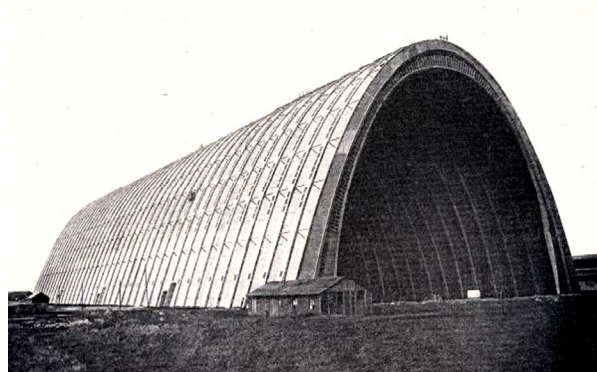


Figure 4.7 | Orly Hangar

Structurally speaking, the Nissen and Quonset huts were corrugated metal panels supported over a steel frame; however conceptually and formally, similar long-spanning metal “surface structures” exist where the articulation of a single skin is the

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<sup>27</sup> Decker & Chiei. Quonset Hut: Metal Living for a Modern Age. New York: Princeton Architectural Press, 2005, p. 148.



only structure. A famous, but atypical example, the Orly hangar has a surface structure of concrete. Back at the domestic scale, Frank Lloyd Wright's Usonian houses used a structural panel consisting of three layers of plywood, though they were not insulated otherwise.<sup>28</sup>

A further derivative structural classification closely related to the "surface structure" is the "stressed-skin panel," or *with insulation*, the Structural Insulated Panel (SIP).



Figure 4.8 | Stacked SIPs<sup>29</sup>

SIPS as they are most often called, emerged in the interwar years and predate Gropius's General Panel. Alden B. Dow, son of the founder of the Dow Chemical Company, experimented with SIPS under Wright, later lamenting their omission from the Usonian Houses.

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<sup>28</sup> Morley, Michael. Building with Structural Insulated Panels (SIPS). Newtown, Taunton Press, 2000, p. 8.

<sup>29</sup> *Ibid*, p. 127.

Typically, a SIP is 1/2" to 5/8" Oriented Strand Board (OSB) with either an Expanded Polystyrene (EPS) or Urethane core. In the U.S., SIPS are available from an ever-increasing number of manufacturers; some the most well known are Winter Panel, R-Control, Premier, and Fischer. Regardless of brand, all of these competing entities use mechanized means to cut "custom" panels (meaning two-dimensional and not square in profile). Despite having already integrated CNC equipment into their production streams, manufacturers have not translated the capacity of this equipment into a next generation product.

This may be in part due to procedural issues. The EPS block used for the core of the panels is typically either cast first using Expanded Polystyrene (EPS), or Extruded Polystyrene (XPS). After creating the core, the OSB faces are pressure-laminated after the application of adhesives. A bonding agent, rather than the natural adhesive properties of the curing foam, is used to attach the OSB facing after the foam has cured.<sup>30</sup> As such, the foam always comes first, and these systems do not break from this established constraint. To whatever confluence this may be attributed, to date industry focus is on competing with established framing typologies, as SIP manufacturers tell it, on "the process of replacing the platform frame."<sup>31</sup> At risk of putting the cart before the horse, casting the foam rather than plating pre-cast foam plays a significant role in the offerings further on.

## **CHAPTER 5 | MANUFACTURED HOUSES**

### **Standardization**

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<sup>30</sup> Morley, Michael. Building with Structural Insulated Panels (SIPS). Newtown, Taunton Press, 2000, p. 27.

<sup>31</sup> Ibid, p. 3.

The postwar housing boom yielded a wide variety of proposals from the likes of architects, engineers, fabricators, and some less merciful entrepreneurs. Out-producing the enemy had just won the war, and in turn, it is no great surprise that an industrial strategy would be put forth to resolve the housing crisis. Aside from innumerable differences in origin and detail, the efforts below all employ the now-familiar “Fordist” methodology of standardization and mass production in their attempts. An irresistible quote used by Kieran & Timberlake when critiquing mass production, Henry Ford is famously to have said that “you can have any color as long as it is black.”<sup>32</sup>

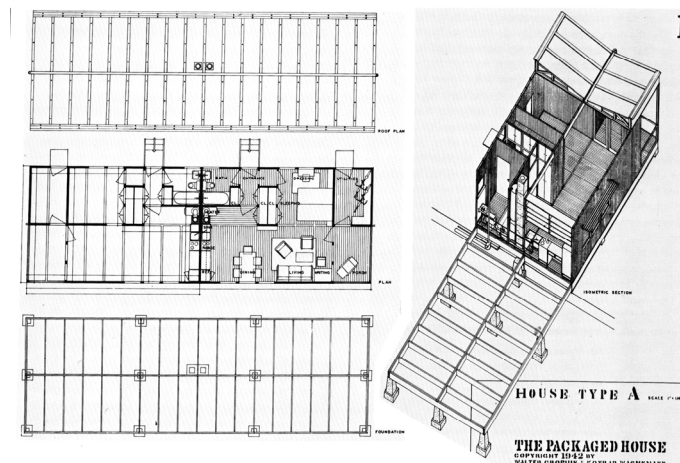


Figure 5.1 | The Packaged House (none made) - Gropius & Wachsman<sup>33</sup>

Walter Gropius and Konrad Wachsman formed General Panel (GP) Corporation in 1946 with a loan from the Reconstruction Finance Corporation (RFC) - the government sponsor of their collaborative work. The image shown above in Figure

<sup>32</sup> Kieran & Timberlake. Refabricating Architecture. New York: McGraw-Hill, 2004, p. 133.

<sup>33</sup> Herbert, Gilbert. The Dream of the Factory-Made House. Cambridge: MIT Press, 1984, p. 260-61.

5.1 is from 1942 and represents their initial collaboration. A subsequent effort, the Growing House, allowed for unlimited growth in its plan, yet this “open proliferation” lacked flexibility and was strictly orthogonal.

Encumbered by both political and personal issues, delays mounted and the effort “ceased to function” in 1950 with the expiration of the contracts with the Veterans Emergency Housing Program.<sup>34</sup> There is currently a General Panel Corp operating, but it has no advertised lineage relating it to Gropius’s defunct one.



Figure 5.2 | Maisons Meudon (25 made) - Jean Prouvé<sup>35</sup>

Mass production raised on pilotis, Prouvé’s inclined axial windows are more than we get from the tandem of Gropius and Wachsman. Apart from their over-reliance on metal, to be forgiven for he was a blacksmith’s apprentice initially, Prouvé had much of it correct. It is simply impossible to represent Prouvé’s work with one image, for the Muedon houses are part of a persistent string of interrelated prototypes. At

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<sup>34</sup> Herbert, Gilbert. The Dream of the Factory-Made House. Cambridge: MIT Press, 1984, p. 330.

<sup>35</sup> Prouvé, Jean. Prefabrication: Structures and Elements. New York & Washington Praeger Publishers, 1971, p. 116.

Atelier Prouve, variation was the mode - especially sectional and structural variation. An inventory of his prototypes and diagrams of systems are included in Appendix A.



Figure 5.3 | Wichita House (2 made) - Buckminster Fuller<sup>36</sup>

Truly visionary, “Bucky” Fuller is a geodesic spaceman of the atomic era, the Wichita House is literally a Beechcraft airplane turned into a house. The form recalls a water droplet, looking as if an Airstream trailer has just fallen out of the sky. The Wichita has high-embodied energy, radial panelization, and epitomizes the machine in the garden.

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<sup>36</sup> Kronenburg, Robert. Houses in Motion: The Genesis, History and Development of the Portable Building. London: Academy Editions, 1995, p. 45.



Figure 5.4 | Lustron Corporation (2,560 made) - Carl Strandlund

All surfaces inside and out of the Lustron houses have the same porcelain-enamel coating; this coating changes color . . . *sometimes*. Industrialist and inventor Carl Strandlund began by manufacturing gas stations, and he produced the Lustrons from a plant in Columbus, Ohio.

In 1948, Strandlund began delivery of 1,800 Lustrons (of the 2,560 total) to Quantico, Virginia, however would eventually file for bankruptcy protection in 1953.<sup>37</sup> One unforgettable quote from a fan states that living in one was “like living inside a lunchbox.”<sup>38</sup> The recent documentary from architect-historian Bill Ferehawk takes a swipe at the Lustron with the tongue and cheek title: “Lustron: The House America’s Been Waiting For.” For those in the Atlanta area, an aging Lustron with the exact color scheme shown above sits on Northside Drive 2 blocks north of Interstate 75.

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<sup>37</sup> Lustron: The House America’s Been Waiting For. Dir. Bill Ferehawk. KDN Videoworks Inc., 2004.

<sup>38</sup> <http://www.piranhagraphix.com/Lustron/> - Accessed on October 20, 2007.



Figure 5.5 | Levittown (17,447 made) - Bill Levitt and Sons

The Levittown Houses built in the mid-twentieth century feature significant variation in plan topology and quantitative program . . . and are thankfully *not* metal. Over the years, Levittown’s inhabitants have gone about their additions and renovations in such diverse ways that the most meaningful variation has actually occurred post facto. In those built after 1950, a TV set (12.5”) was included in the space under the living room stair. Deployed in bulk like the Lustrons, the Levittown Houses are located at a former potato farm on Long Island outside New York City.

With the exception of the Wichita House, these are all what Robert Kronenberg calls “demountable buildings” that are “transported in a number of parts to the site” and “may be further divided into deployment categories.”<sup>39</sup> This terminology is important because prefabrication, a property of each house shown, does not necessarily imply a portable structure. The association of prefabrication with modularity is partly to blame for many curious proposals where privacy and, partitions have been flatly dismissed. During the sexual revolution of the 1960s, such programmatic leaps in reverse might have played well, as pneumatic houses even did for a bit.

<sup>39</sup> Kronenberg, Robert. Houses in Motion. London: Academy Editions, 1995, p. 7-8.

Laugier himself might approve of such domestic primitivism, but he too would grow weary of the parade of huts, yurts and igloos that continue to be proposed.



Figure 5.6 | Igloo House - Wagner<sup>40</sup>

It is in reaction to our tendency to test our prefab ideas on the pod that the houses presented in this work eschew the tradition of portability and are not portable capsules for the American dream. The Turnstijl houses are happily static, demonstrating how *custom prefabrication* does not have to so thoroughly mobile as mid-century prefab was. Although the pre-assembled components are not quite “grand blocks” on “the goliath scale of shipbuilding,” they do come in “chunks” *just portable enough* to be brought to you.<sup>41</sup>

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<sup>40</sup> Herbert, Gilbert. The Dream of the Factory-Made House. Cambridge: MIT Press, 1984, p. 237.

<sup>41</sup> Kieran & Timberlake. Refabricating Architecture. New York: McGraw-Hill, 2004, p. 73.





Figure 5.7 | Apollo Capsule or Primitive Hut?

Admittedly, some of the best of these mid-century efforts did move a few thousand units, but the real legacy of the factory-made house is inexorable from with the now-apparent shortcomings of Modernism. Traditionalist Stephen Mouzon captures this sentiment in a chapter appropriately titled "Story of Languages of Arch."

*Modernist architecture on the other hand, has always been focused on the machine. Much of the idealism was based on the notion that mass produced buildings would save the world's working classes from their perceived miserable existences at the time by providing cheap, quickly produced housing. The actual buildings were based more on the aesthetic of mass production, which is a crucial difference. The only manifestation of true mass produced buildings is the ubiquitous mobile home, which might therefore be considered the highest form of Modernist architecture.<sup>42</sup>*

Begrudgingly, a degree of what he says is sadly true - the "singlewide" and "doublewide" are the most prolific manufactured houses of our time. When observed

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<sup>42</sup> Mouzon, Stephen. Traditional Construction Patterns. New York: McGraw-Hill, 2004, p. 11.

by most, these are not at rest, but are polyethylene-clad on the way to a KOA site somewhere.

Digression aside, Mouzon accurately identifies that rooted within the recurring dream of prefab is the fallacy that some universal system may rescue us from more helpings of the same. A physical manifestation of this same ideal, appropriately named the “Universal Joint” was used in General Panel partitions and is a quintessential artifact of standardization – due to its maximum complexity and minimum impact.<sup>43</sup> As much as we agree with the characterization that the dream of the manufactured house can “be the silver bullet that solved social problems by providing quality affordable houses for the common man,” we must adjust our tactics for the present.<sup>44</sup> It is, rather, that this dream remains valid, but the aesthetic and basic modularity of Fordism that has been proven unsound.

Mouzon’s usage of the mobile home to lament Modernism shows avarice, but the real foes he should consider are mass production and the production methodology of the day. In fact, the commercial success of such inferior products is proof of nothing if not demand! Eschewing the wonton historicism Mouzon would likely espouse, it may be worth spending some time on where we are heading. The reason for this being that the potential of *digital* production methodology and mass customization cannot be lumped in with past results, and this tandem is due their chance. It already seems unlikely that they will result in the same aesthetic objections, for they promise both variety and form in places where only uniformity once reigned.

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<sup>43</sup> Herbert, Gilbert. The Dream of the Factory-Made House. Cambridge: MIT Press, 1984, p. 273.

<sup>44</sup> Lustron: The House America’s Been Waiting For. Dir. Bill Ferehawk. KDN Videoworks Inc., 2004.

## CHAPTER 6 | DIGITALLY MANUFACTURED HOUSES

If studios in architecture schools (from Columbia, Georgia Tech, Texas and Yale) are legitimate leading indicators, there has been a resurgence of interest in the manufactured house lately. The Sears & Roebuck catalog is, of course, no longer the venue and has been supplanted by the internet. Prefab fan sites that rank, collect, comment, and publicize the efforts have sprung up (e.g., [prefabs.com](http://prefabs.com), [fabprefab.com](http://fabprefab.com), and [inhabitat.com](http://inhabitat.com) to promote some of the best). Beyond academic speculation, this is actual competitive behavior whose observable excess is more than just another passing trend. The myriad of offerings, in fact, echoes rhetoric issued over a decade ago by B.J. Pine.

*In this new frontier, a wealth of variety and customization is available to consumers and businesses through the flexibility and responsiveness of companies practicing this new system of management<sup>45</sup>*

Although Pine directs this quote from 1993's Mass Customization at the corporate community, it emphasizes that the burden of “responsiveness” lies with the producer. Indeed we now have “prosumers” (a term Pine coined to describe a more participatory consumer) seated at their PC, but they must be activated by the product being offered.<sup>46</sup> From the point of view of the producer, this breed of consumer can only exist if the variability of a given offering is sufficiently integrated with production to enable the prosumer's behavior.

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<sup>45</sup> Pine, B.J.. Mass Customization. Boston: Harvard Business School Press, 1993, p. 7.

<sup>46</sup> Ibid, p. 194.



Figure 6.1 | Flatpak - Lazor Office

One of the most well known, but woefully mid-century, of the contemporary prefabrication efforts, is Flatpak. Named for its shipping method, it uses the 4' x 8' and 4' x 4' panels as its primary modular component. Generally, these houses feature less metal, more wood, and are characteristically revisionist, taking on the modernist aesthetic. The debt to the Eames's own case study house is obvious, but there are some significant departures including the site-cast concrete base, and the increasingly elaborate animations at [Flatpak.com](http://Flatpak.com).

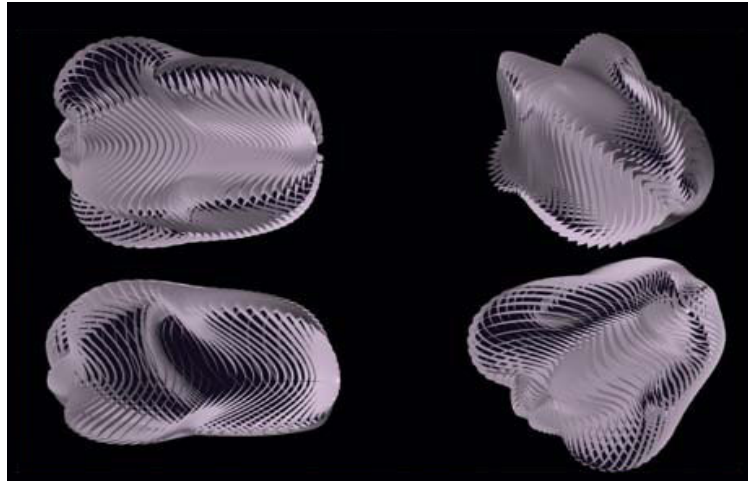


Figure 6.2 | Embryological House - Greg Lynn

In stark contrast with Flatpack, the Embryological House (Figure 6.2) creates brand identity out of global formal variation *and* local variation of the “shredded” skin. In the prologue of *Architectural Laboratories* Lynn states that “no two houses are ever ‘identical’ and that there is no “ideal or original.”<sup>47</sup>

Nearby Lynn issues a specific critique of Modernism saying that “the banal Modernist notion of generic housing involved the invention of a mass-produced existence minimum structure to which customizations, additions, modifications, or alterations could be made by the addition of parts or components.”<sup>48</sup> Such thoughts emphasize how individuality is not purely an additive act, and may result from intentional variability that is built-in.

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<sup>47</sup> Lynn and Rashid. *Architectural Laboratories*. Rotterdam: Nai, 2002, p. 11.

<sup>48</sup> *Ibid*, p. 12.

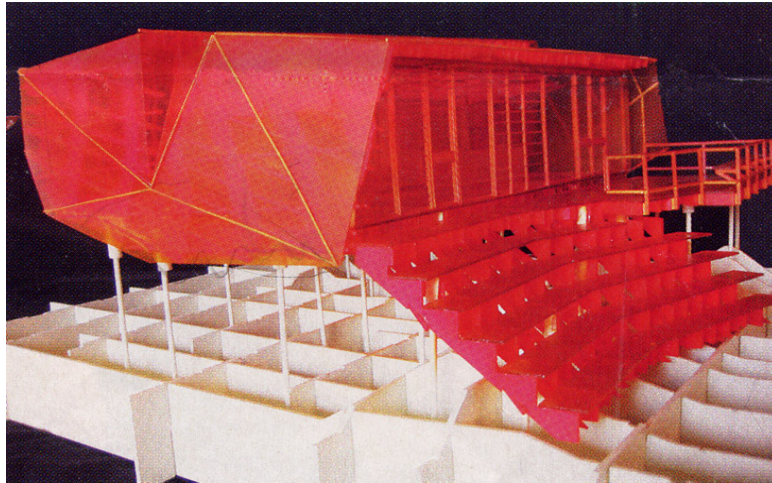


Figure 6.3 | Parish House - SYSTEMarchitects

The Parish house was conceived via an iterative process using a lasercutter, featuring slotted prefabricated parts and an exterior envelope of plywood stressed-skin panels. Wartime opportunism drove the last round of prefabs; a hurricane, flood insurance premiums, and SketchUp drove this one.



Figure 6.4 | Turbulence House - Stephen Holl



Stephen Holl's Turbulence house is a slightly crinkly example of custom prefabrication used in a residential application. Although aluminum, this 900 square foot guesthouse was erected in only six days from 24 stressed-skin aluminum panels.

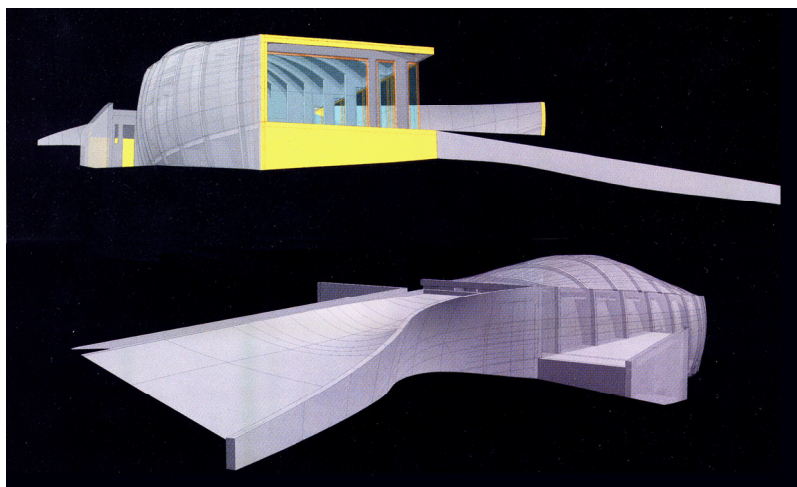


Figure 6.5 | Big Belt House - Bill Massie<sup>49</sup>

Bill Massie's Big Belt House (Figure 6.5) was cast on and off site using both milled-foam forms and machine-scored OSB formwork. The house's name is derived from the interlocking precast ribs (the principal prefabricated element) whose detail recalls a jigsaw puzzle piece or belt clasp. The impressions left by the machined foam on the sink, and the form ties on the beams adorn the surfaces of the concrete castings.

Throughout this field of contemporary precedent, we find the architects using pre-assembly and digital fabrication technology to achieve customization. With the exception of Lazor Office, each architect has also chosen to update the form.

Flatpak's take is likely more fiscally realistic than the rest, and is not a one-off like some, but it does not take sufficient advantage of the assets of modern production

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<sup>49</sup> Architectural Design Vol. 72 #5. "Versioning" West Sussex: John Wiley + Sons Ltd., Sept/Oct 2002.

methodology. Having what Ulrich and Tung would call “common components” with only “bus modularity,”<sup>50</sup> Flatpak simply fails to engage the same challenges as the others. A harsher admonition of this behavior is offered in the Atlas of Novel Tectonics, which best articulates the architectural tendency to update the theory and not the product.

*The Apologists for Modernism [...] are in grave error. In their minds the shifting paradigm is simply yet another shift in discourse, it doesn't affect the object, and the object has no effect on it.*<sup>51</sup>

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<sup>50</sup> Kratochvil, Milan. Growing Modular. Heidelberg: Springer Berlin, 2006, p. 86.

<sup>51</sup> Reiser and Umemoto. Atlas of Novel Tectonics. New York: Princeton Architectural Press, 2006, p.24



## CHAPTER 7 | MASS CUSTOMIZATION AND CONFIGURE-TO-ORDER

A new book on mass customization, Growing Modular, examines the popularization and development of Mass Customization following Pine's 1993 book. In the preface, author Milan Kratochvil offers some complimentary how-to advice.

*The fast lane to mass customization of complex offerings is the definition of modular product packages, and their subsequent configuration on demand, to fit customer specific needs. This approach is usually called Configure-to-Order.*<sup>52</sup>

Beyond instruction, these words also serve to remind us that the term mass customization really describes an effect and is not, itself, a specific strategy. Above, only Configure-to-Order is named, but later in the work, Kratochvil discusses two other conceptual strategies for achieving customization. In Section 2.2, he details all three: Assemble-to-Order (AtO), Engineer-to-Order (EtO), and Configure-to-Order (CtO). These first two approaches are relevant to the extent that they resemble delivery strategies already familiar to the architect, i.e., mass production's standard component modularity, and closer to home, the Design-Bid-Build delivery method.

Without going too far into each, Assemble-to-Order (AtO) uses "standard level components that are pre-assembled to form large, high-level components.

Consumer choice is usually restricted to a limited predefined set of product lines."<sup>53</sup>

One example given is the car, in which "variance is kept small" causing us to recall Lynn's objections about the limitations of strictly additive systems.

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<sup>52</sup> Kratochvil, Milan. Growing Modular. Heidelberg: Springer Berlin, 2006, p. 23.

<sup>53</sup> Ibid, p. 24.

Of Engineer-to-Order (EtO), Kratochvil states that “cost and time estimates are kept hazy” and that many components are developed specifically for an order with little pre-assembly. The variant finally delivered is the result of a full-scale project.”<sup>54</sup> The hazy costs and deadlines sound a lot like the controlled-disorder of architectural projects, but the examples Kratochvil gives are vessels, defense systems, offshore platforms, and software packages - all are items on a grander scale than houses.

Finally, of Configure-to-Order (CtO), Kratochvil asserts, “this concept uses components, often with some pre-assembly, and with variance built into the product, usually at the last steps of the production and deployment process.”<sup>55</sup> The name, he says is meant to imply that we should “compete by customization, rather than trying to struggle with it.” At first glance, this kind of flexibility seems achievable for small-scale products (e.g. personal computers), but can such a strategy operate at the scale of architecture? The systematic customization of a house seems a reasonable place to test such ideas. In any case, these are still just conceptual guidelines, so how exactly can do we build variability into a house?

The short answer to this is *modularity*, but certainly it is a more complex and diverse modularity that the mid-century prefabbers previously conceived. Early on, Kratochvil makes the delicate point that “product customization can be achieved through methods that range from ‘one of a kind’ design through to the *adaptation and modification of a standard product* to meet a specific customer’s needs.”<sup>56</sup> In Section 5.6, he continues the discussion of different types of modularity and includes three different systems of classifying modularity, which may be found in Appendix D.

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<sup>54</sup> Kratochvil, Milan. *Growing Modular*. Heidelberg: Springer Berlin, 2006, p. 84.

<sup>55</sup> *Ibid*, p. 85.

<sup>56</sup> *Ibid*, p. 5.

Looking at these attempts to parse modularity, we realize that our task is to debase the typical pluggable-swappable, or as he calls it, the “Lego Generation’s”<sup>57</sup> interpretation of modularity. This can be translated into a preliminary design question, i.e., must modularity always, as the Lego implies, be a unit of construction?

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<sup>57</sup> Kratochvil, Milan. *Growing Modular*. Heidelberg: Springer Berlin, 2006, p. 9.

## **PART TWO – PELIMINARY EXERCISES**

## CHAPTER 8 | TYPE DEMATERIALIZED

It is with this deeper conception of modularity in mind that we return to the shotgun house and its properties that we have already discussed at length. If one of its properties (i.e., material) becomes modular, how does this affect the type as we know it? If a straight single-loaded circulation schema is considered the only ontological property of a type, will maintaining it alone be enough keep it seated within the category? If so, how far can we go? The following three figures show a typical shotgun where material is treated as a non-schematic (non-essential) property that may modulate. These wood, metal, and plastic shotguns have been “Configured-to-Order.”

### Exercise 1: Materially Diverse Shotguns

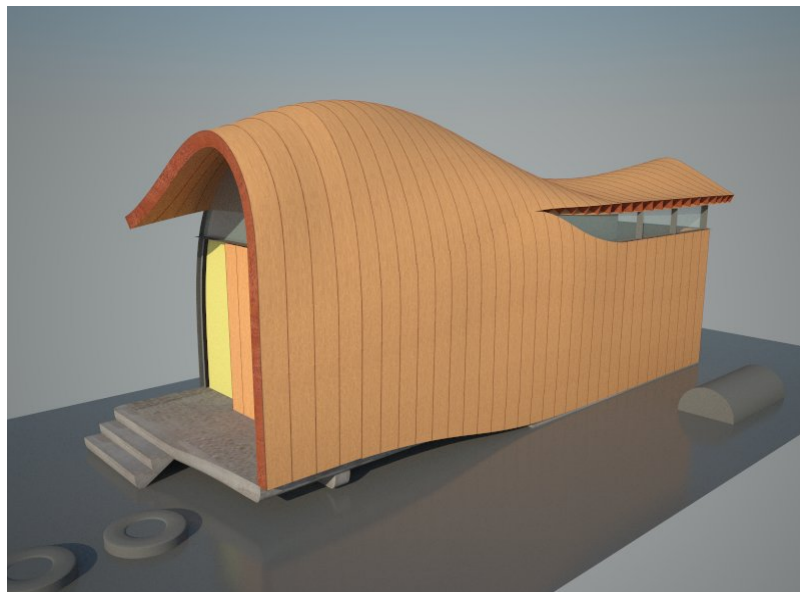


Figure 8.1 | Plywood Shotgun - Aeck



Figure 8.2 | Metal Shotgun – Aeck

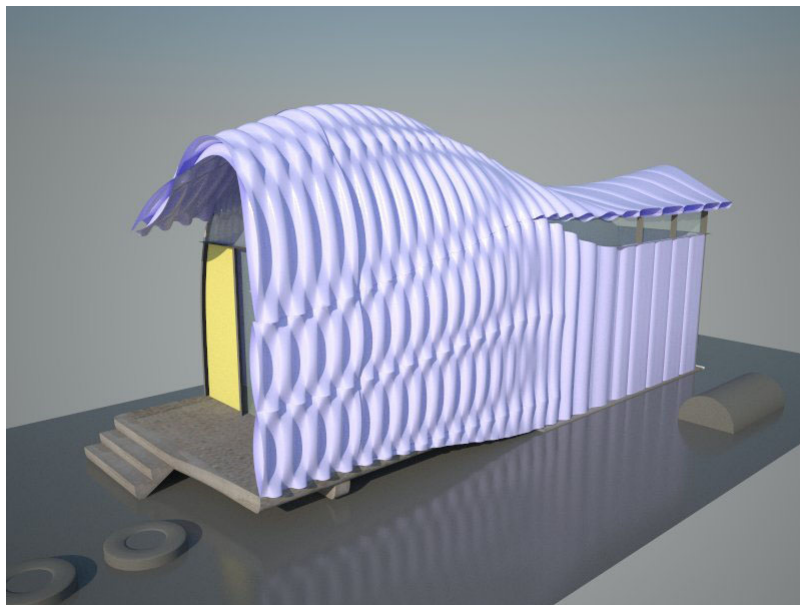


Figure 8.3 | Plastic Shotgun - Aeck

These “materially diverse” shotguns demonstrate type’s resilience as well as the potential of reviving past types. The variation produced here is non-essential,

begging the question of whether the increased capacity of new production methodology will yield its own unique schemas.

At this point, it is also important to recognize that much like production methodology, materials are undergoing a technological revolution of their own. The running theme of increased capacity allowing variation is also applicable to them. As an example, the forming that would be required to make the third figure would certainly be inconceivable without thermoplastics. Just imagine a Bakelite shotgun, the only polymer that approaches its age. To explain these three figures in terms of their structure class, the first shotgun remains a “stressed skin panel” throughout, while the second two figures show a state change from “sheathed frame” to corrugated “surface structure.”

## CHAPTER 9 | THE TURNSTIJL HOUSES



Figure 9.1 | Branding

The Turnstijl Houses have their own branding; the first word *turn*, is referring to change, and the second, *stijl*, to their departure from the planar, standardized, constructivism characteristic of early modernism. The neoplasticists were one of modernism's primary theoretical influences, and thus the reference to de Stijl (the style) in the branding. In contrast to the oppressive panelization, rigidly orthogonal plan topology, and kit-of-parts strategy of previous efforts, each Turnstijl house is created from unique parts and is formally organic. The acts of selection that occur during its phased breeding allow the personalized configuration of a house at different points during its conception. This exercise attempts to embody the Configure-to-Order approach by systematizing the creation of blended house schemas and developing means to involve the prosumer in every decision along the way. Please refer to Appendix B for larger versions of the following Figures.



## Exercise 2: Schema Variation

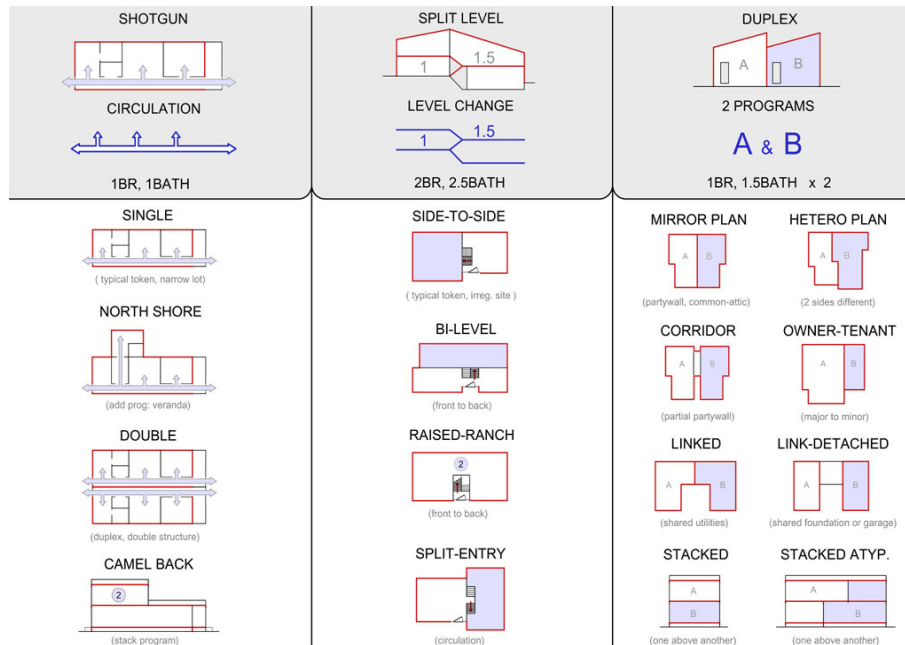


Figure 9.2 | Phase 1: Inventory of Sub-Type - Aeck

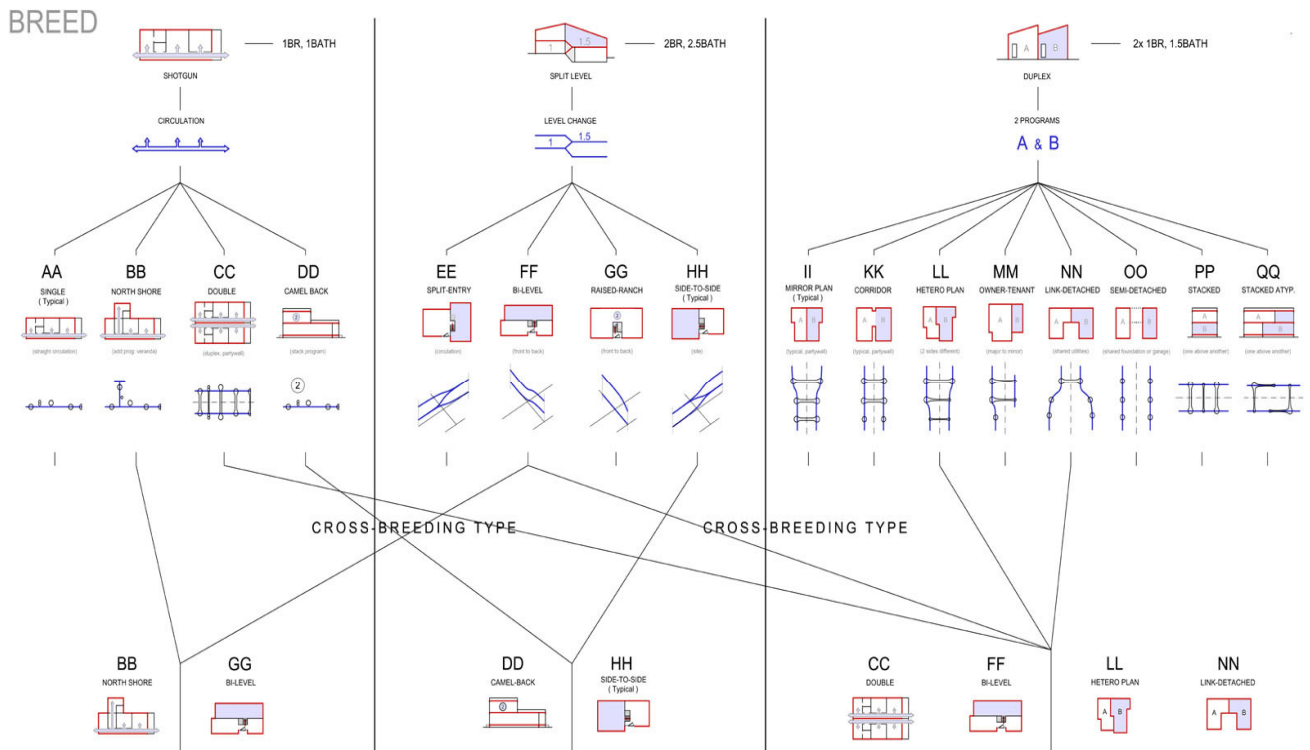


Figure 9.3 | Phase 2: Selection and Abstraction of Schema by Sub-Type - Aeck

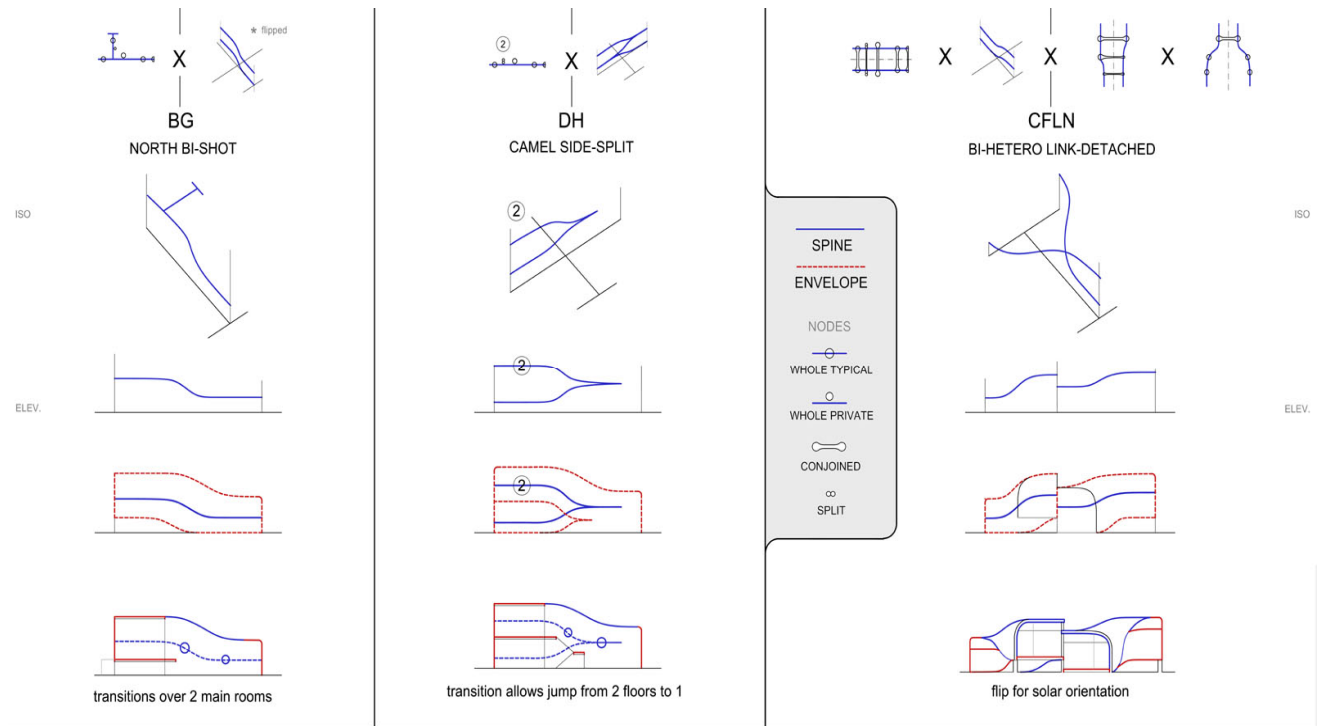


Figure 9.4 | Phase 3: Breeding in Abstraction - Aeck

The variation created by this system occurs on two levels; the first is on a logical-topological level where the schema is manipulated. This starts with the sub-type inventory, then in abstraction, diagrammatic representations of the level-change, circulation (shotgun), and duplex schemas are crossbred or combined. Part in parcel to the manipulation of type is the specification of different amounts of program. This is included to demonstrate that schema blending is scale-less, and independent of programmatic properties.

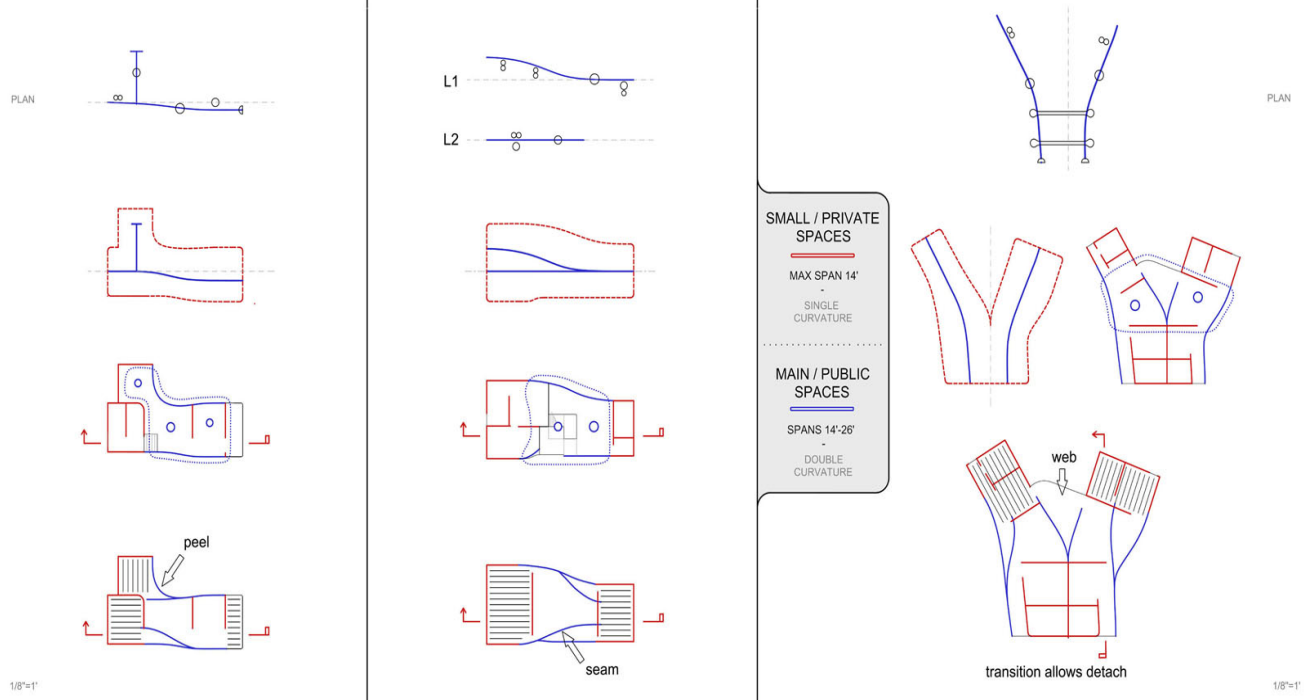


Figure 9.5 | Phase 4: CFS Application - Aeck

## FINAL PLANS

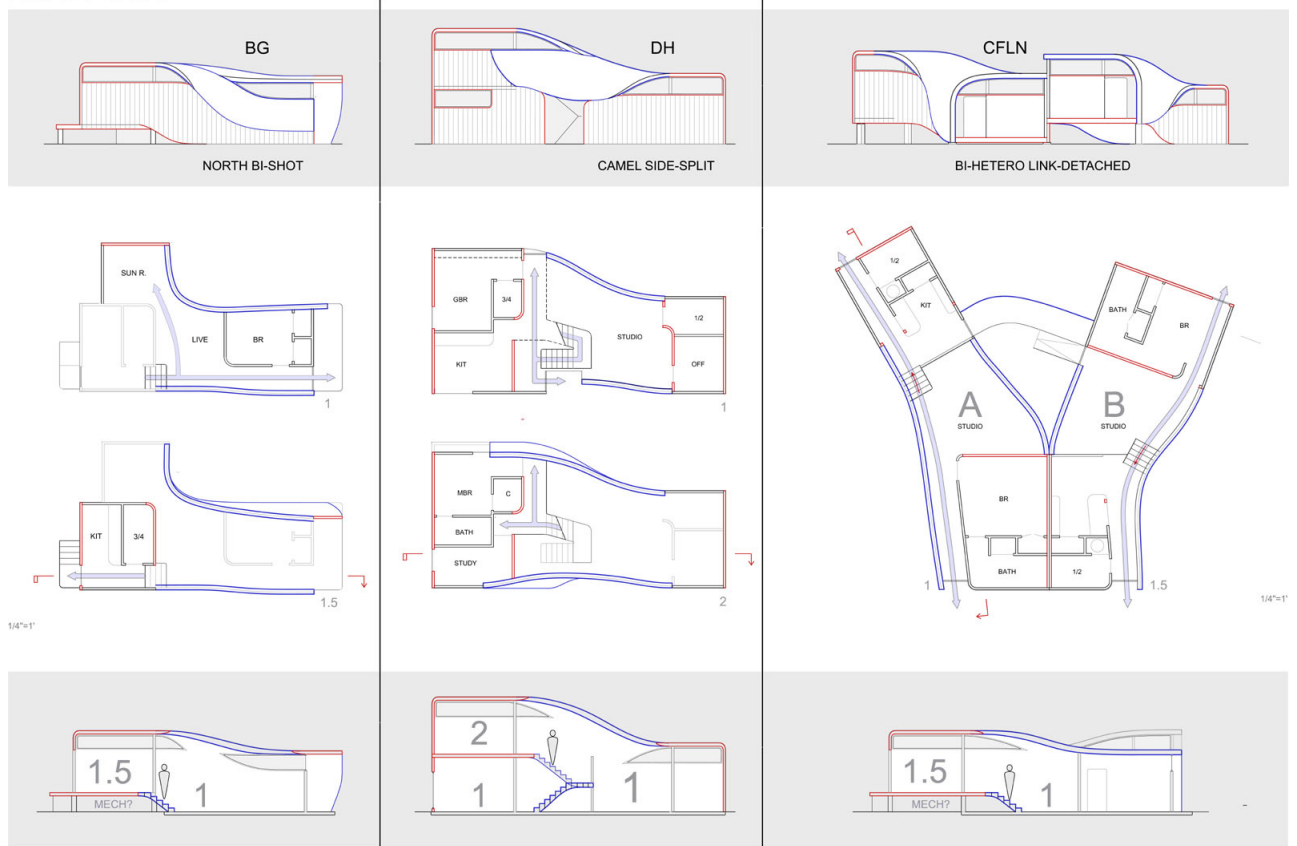


Figure 9.6 | Phase 5: Three Outcomes - Aeck

The second area of variation occurs at the level of structure class. In each house, the public rooms and circulation paths were identified as areas where doubly curved surfaces would be the most desirable, and are signified by the nodes in Figure 9.4. The public spaces are also the largest spaces in all three houses, so naturally correlate with the longest spans. The double blue lines in Figure 9.5 represent the areas where the system transitions from “ribbed shell” to doubly curved structure.

### Exercise 3: Outcomes

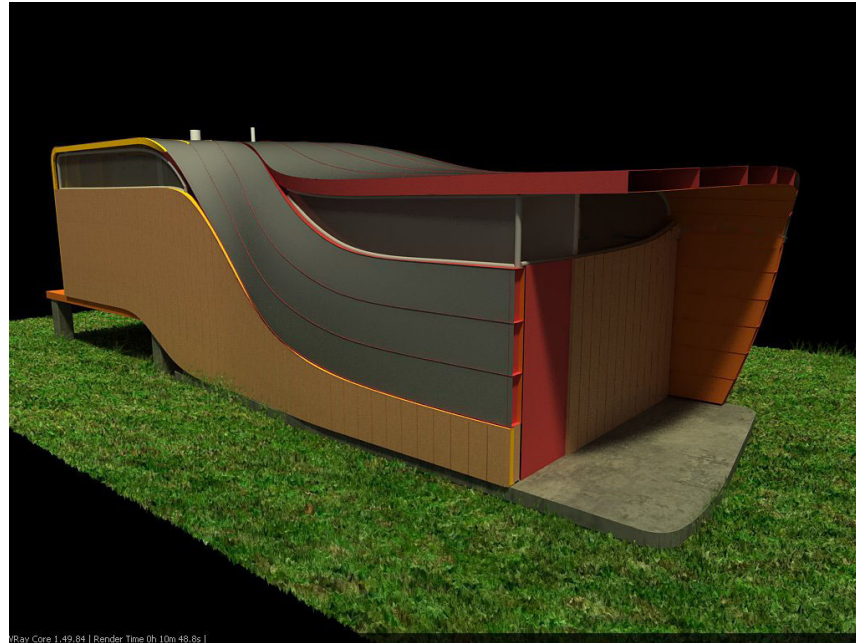


Figure 9.7 | Turnstijl Outcome A: “North Bi-Shot”



Figure 9.8 | Turnstijl Outcome B: “Camel Side-Split”

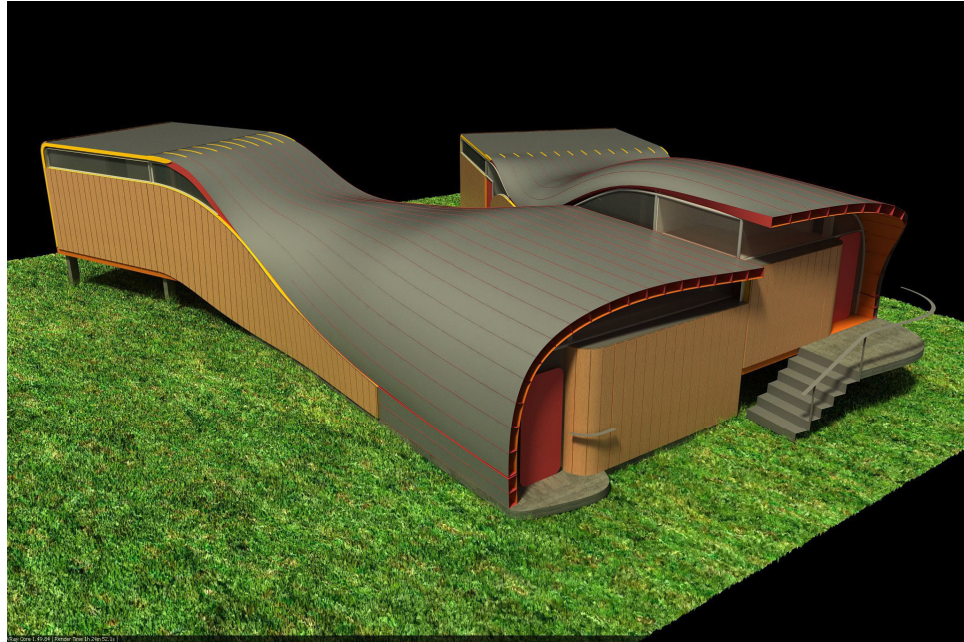


Figure 9.9 | Turnstijl Outcome C: “Bi-Hetero Link-Detached”

#### Exercise 4: Structural-Aesthetic Variation

In this third exercise, variation is developed by manipulating the behavioral properties of the panelized system. The three examples below range from purely *aesthetic* in the first figure (i.e., random panelization) to *practical* in the case of the third (i.e., curvature-based panelization). This is a structural-aesthetic variation where the seams of the plywood formwork, which must exist anyway, are designed. The sectional variation has been eliminated for clarity. Decisions such as what direction it runs, what percent curvature it has, and how it relates to the overall form all become parametric. In an attempt to reduce the numbers of variables in play (and avoid exhausting the shotgun), Outcome B from the previous exercise is used as a vessel for this final exercise.





Figure 9.10 | Random Panelization



Figure 9.11 | Diagonal Panelization



Figure 9.12 | Curvature Based Panelization

### **PART THREE – THE CANNOLI FRAMING SYSTEM (CFS)**



## CHAPTER 10 | FRAMING THE PROBLEM (CFS)

The enduring question that arises on this safari through type, house typology, and structure class is what may be conceived that can affect all three? Specifically, the final problem of this research is to design a framing typology that is capable of both formal and structural variation. If defined using the specific definitions of modularity as outlined in appendix D, the system that is proposed would be a “variable component-dimension, standard component” with “sectional modularity.”<sup>58</sup> A number of conceptual realizations became evident along the way and became the criteria for the system as Table 10.1 shows. In the second column, the motivation behind each is classified in order to reveal the diversity of the group.

Table 10.1 | Conceptual Assumptions

Assumption	Motive
Wood ( . . . people want wood houses)	Material
Maximize the usage of thin materials 1/2” and under.	Efficiency
Be capable of both typical & long spans.	Structural
Approximate double curvature.	Formal
Avoid exhausting & costly surfacing on the mill.	Fiscal
Be affordable.	Fiscal
Change structure state.	Structural
Be Green.	Environmental
Reduce usage of metal fasteners & nails.	Efficiency

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<sup>58</sup> Kratochvil, Milan. Growing Modular. Heidelberg: Springer Berlin, 2006, p. 84-85.

## CHAPTER 11 | PROCESS (CFS)

### Material Dimensions

The first in the series of considerations on the way to the final proposal were the dimensions of standard materials. The lengths of each component of the system are sized based on how they will fit on a 4'x8' sheet. Specifically, the pieces involved in the middle or “transition section” (where the change from stud-to lam occurs) never exceed 4' (i.e., the short direction of a sheet). In the long direction, another example is that the both the “faces” and “ribs” of the tube are always under 8'. These considerations become especially significant in the aggregate after all parts are sorted by material thickness. We used nesting software (RhinoNest) to calculate minimum material usage. If capital were unlimited, these decisions could be modified for larger router beds or material sizes. For instance, 8'x24' is a common panel dimension in the SIP industry. Nevertheless, what is presented here is based on standard retail materials and the equipment used to produce the mockups.

### State Change

The CFS, though comically named, performs in several ways beyond its obvious capability of greater formal continuity. The most conspicuous area of “performative variability” is its ability to change structure state. This transition from a stud wall to “ribbed-shell” is practical for long span conditions and situations where the approximation of double curvature is desirable for either spatial, span, or formal reasons.

By contrast, the stud half of the system is only capable of single curvature, but has the advantage of being more or less dense for point loads or to framing openings. In certain conditions where no transition or curvature is needed (e.g., partitions and gable walls), the studs may simply become widely spaced serving as splines to join adjacent panels together.

### Insulation

When in “ribbed shell” state, the 9” (6” in the hollow core) of rigid foam serves simultaneously as structure and insulation. The wood tube is essentially permanent formwork for sprayed foam, so the R-value of the section will clearly exceed current standards. For example, a conservative R-value for one inch of foam is roughly 4, so an estimated R-value for the section is 36. The best BATT insulation typically does is 22, and this assumes perfect installation and complete coverage.

Expectedly, the tolerances of a digitally manufactured panel system would also exceed that of conventional framing, and presumably, infiltration would also be minimized.



Figure 11.1 | Associative Branding

### Branding

The branding of the “Cannoli Framing System” is based on the analog of the rigid foam and plywood tube to the cream-filled Italian dessert as is shown in the image above.

Of branding, activist and author Naomi Klein says, “In a consumer-driven society, brands are the main source of identity. The brand fills a vacuum and forms a kind of armor, taking over the part once played [by] political, philosophical, or religious ideas.”<sup>59</sup> Developing an identity for the product does not fall outside the purview of the architect, and is far from needless commercialism. The favorable branding of an architectural idea may positively influence its consideration, and if anything, that positive influence *increases* the chance that an architectural idea may actually be realized. Even Klein relents when the branding is actually embodied by the product:

*I don't think there is anything wrong with logos, with doing whatever is necessary to get your message out. Among some of the people who share my ideas, there's an attitude that the act of selling is somehow dirty. But I think that if*

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<sup>59</sup> Klein, Naomi: No Logo: Taking Aim at Brand Bullies. Knopf Canada, 2000, p. 236.

*you're actually selling what you are claiming to sell, then  
it's fine. I have a problem when there is a betrayal of  
the message.*<sup>60</sup>

Kratochvil also discusses branding as part of his strategy for achieving “customer intimacy” naming four related parts: “product supremacy, service supremacy, brand focus, and dialog focus.”<sup>61</sup> The last of them, “dialog focus” represents the interaction of the consumer with the product - the diagrams in Exercise 3 represent the *design dialog* a consumer would engage when generating their own house. The actual means of making this process interactive would involve, presumably, some sort of web-based graphical user interface (GUI), which would have to be developed to deploy such a system.

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<sup>60</sup> Sittenfeld, Curtis. “Fast company” Issue 38 August 2000

<sup>61</sup> Kratochvil, Milan. Growing Modular. Heidelberg: Springer Berlin, 2006, p. 15.

## CHAPTER 12 | THE SYSTEM (CFS)

Please refer to Appendix C for full-page sections and elevations of the system.

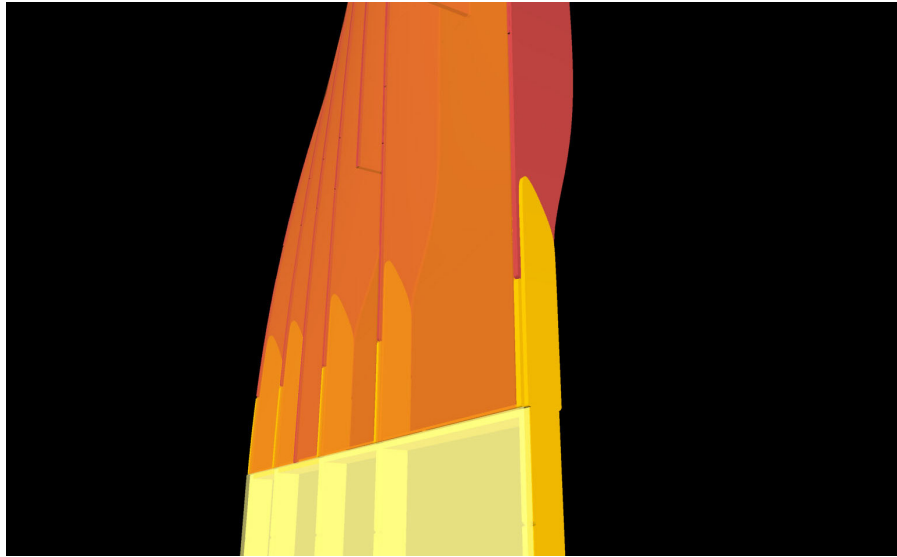


Figure 12.1 | CFS: State Change

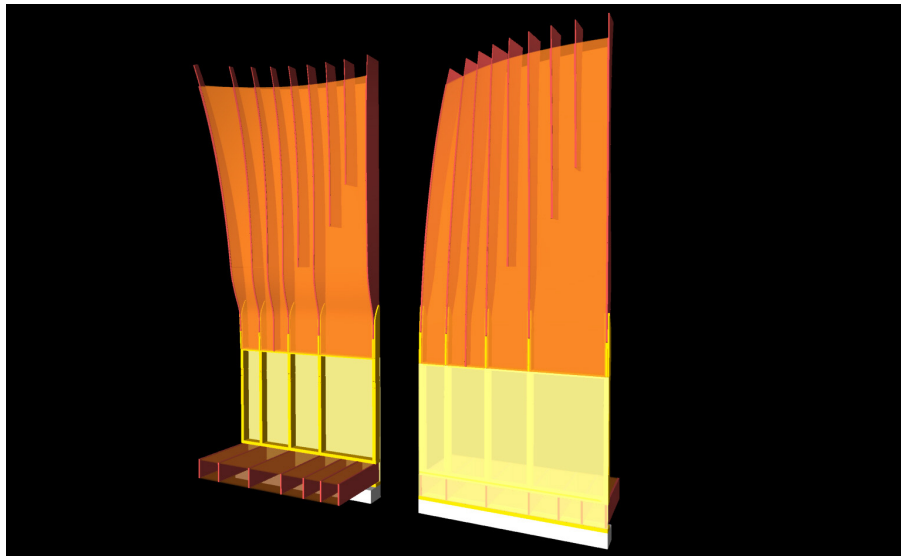


Figure 12.2 | The CFS

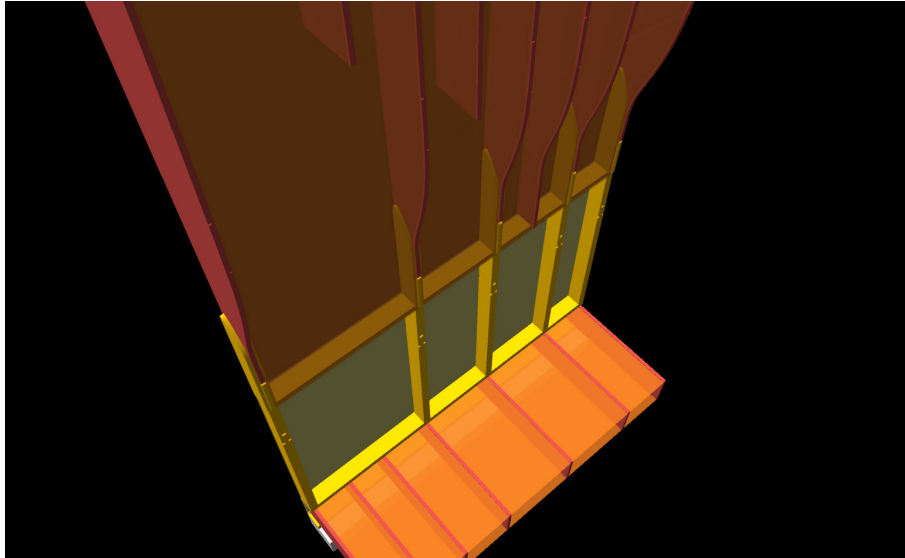


Figure 12.3 | The CFS

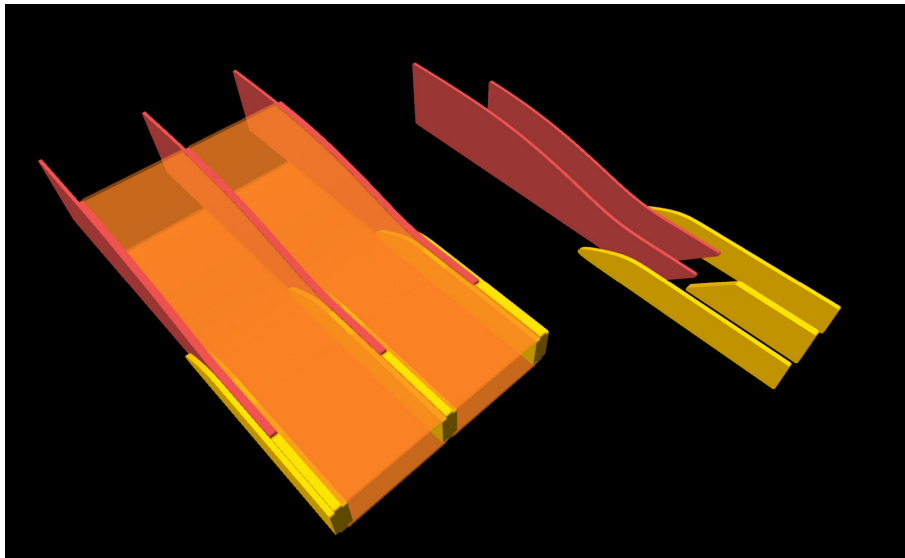


Figure 12.4 | The CFS

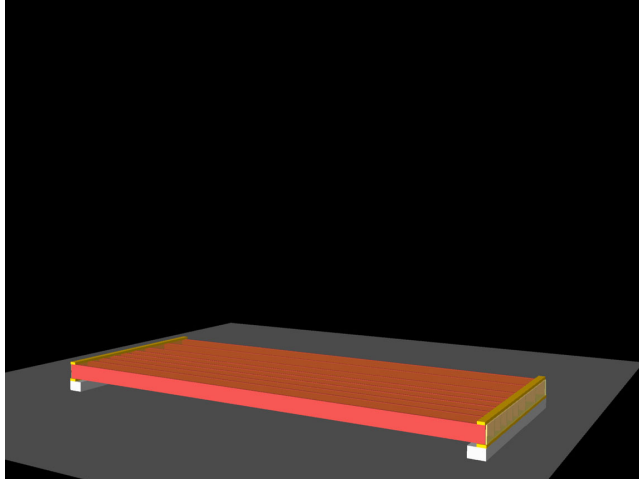


Figure 12.5 | Site Assembly 1

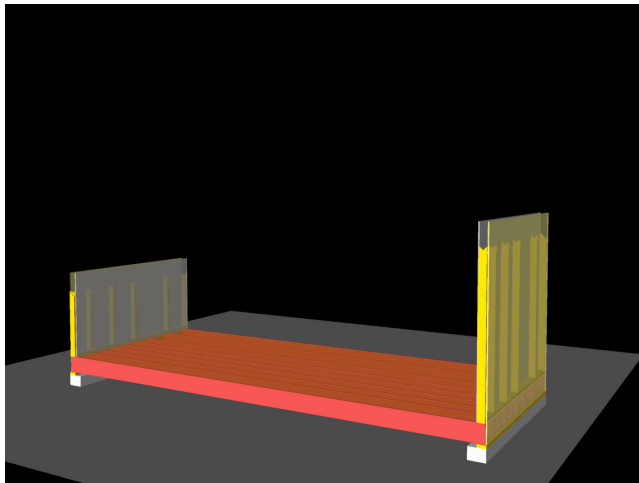


Figure 12.6 | Wall Panels - Site Assembly 2

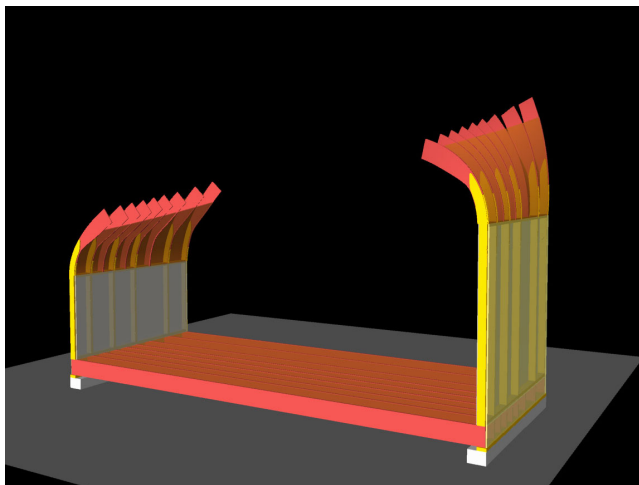


Figure 12.7 | Assembly 3



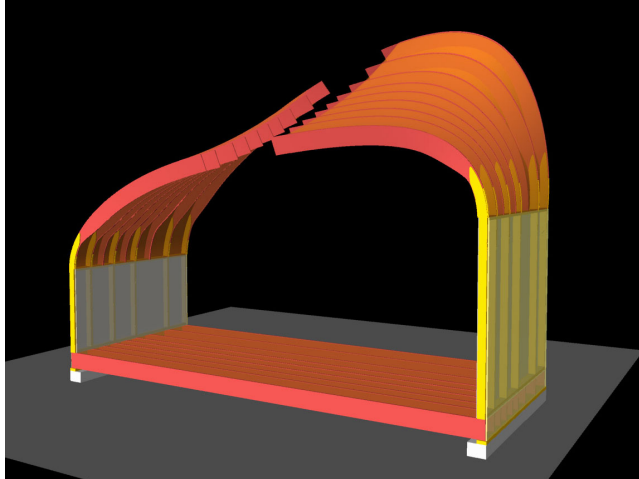


Figure 12.8 | Site Assembly 4

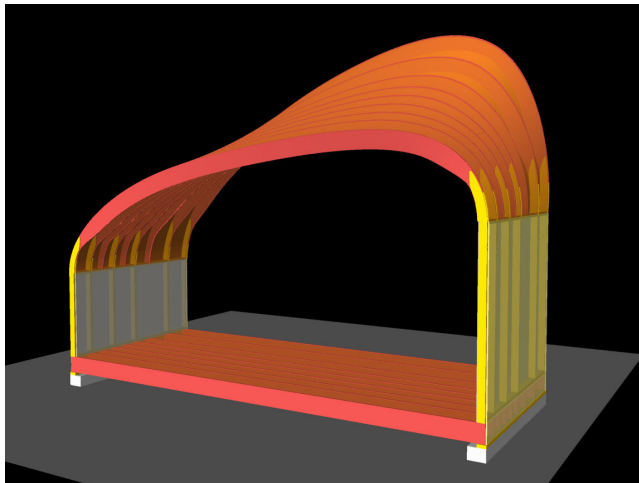


Figure 12.9 | Site Assembly 5

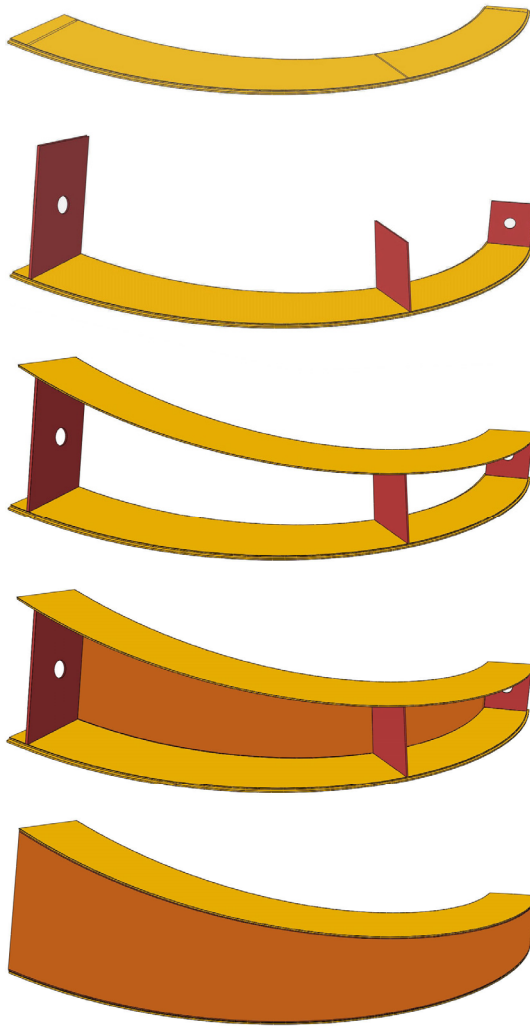


Figure 12.10 | Component Assembly Order

## CHAPTER 13 | PROCESS MODELS

The strategy for physically achieving the objectives found in Figure 10.1 was attrition by way of recursive physical models and mockups Figures 13.1-13.6. In the majority of cases, fabrication geometry was created from the same three-dimensional models used to either render or initially conceive the prototype. Some minimal offsetting for material thickness was necessary to create toolpath-geometry for full-scale work, but in most cases, all three-dimensional work is scalable and multi-purpose.

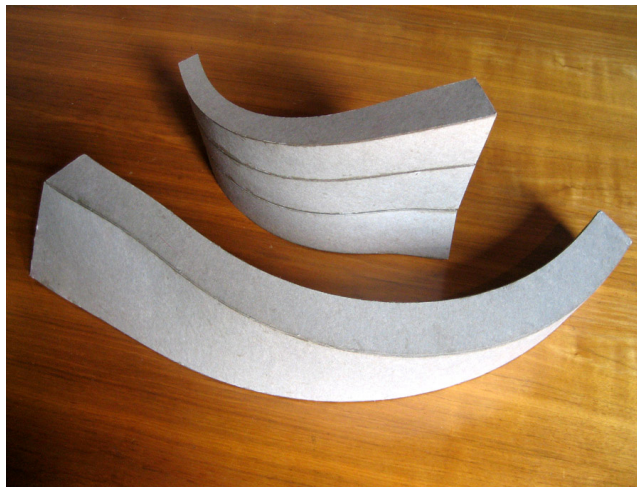


Figure 13.1 | Three Tubes - Exterior @ 1/2"=1'

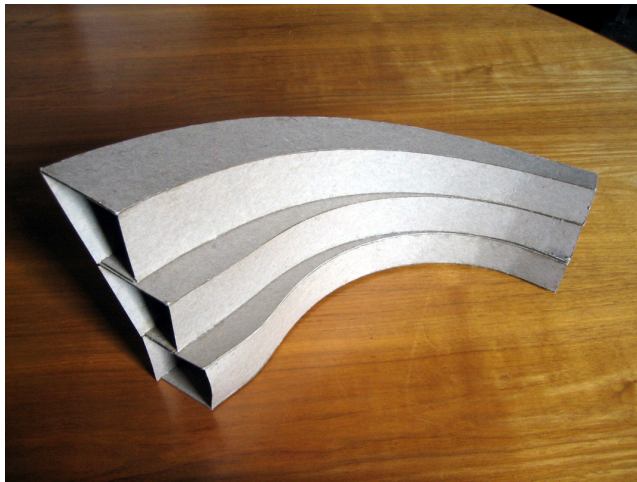


Figure 13.2 | Three Tubes - interior @ 1/2"=1'

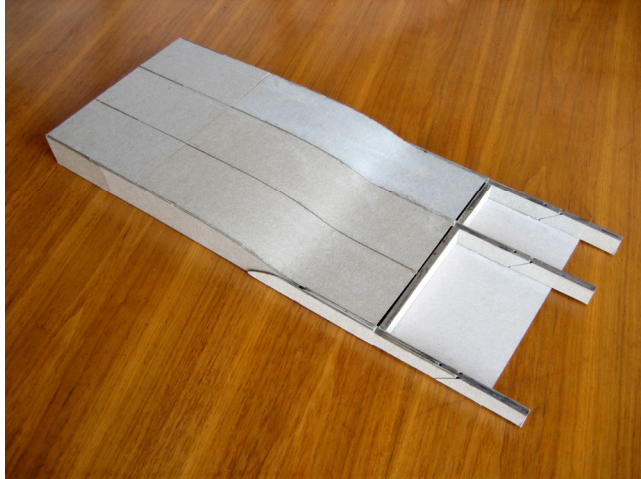


Figure 13.3 | Transition - Joinery Closed

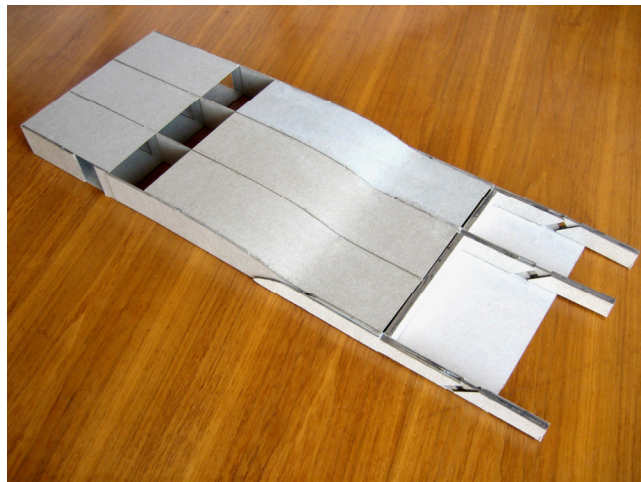


Figure 13.4 | Transition - Joinery Open



Figure 13.5 | Transition Detail

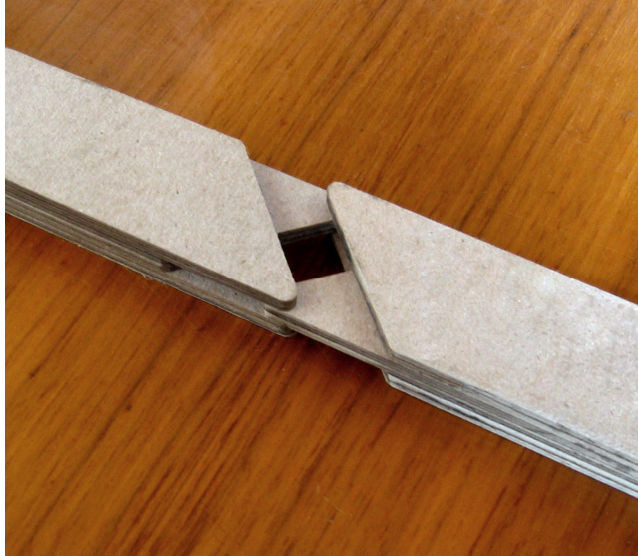


Figure 13.6 | Lam-Stud Joint

## **PART FOUR – FABRICATION & TESTING**

## CHAPTER 14 | FULL-SCALE PROTOTYPES

### Digital Methodology

All-digital processes were used to create the models and mockups presented by this thesis. The chipboard models that follow were cut on a Universal Laser Systems (ULS) X-660 Lasercutter. The three-dimensional work was created using Rhino 4 and was rendered in V-Ray and Penguin. The Advanced Wood Products Lab (AWPL) at Georgia Institute of Technology (GaTech) made the time on a Morbidelli Author 3-axis router for the full-scale prototypes and final prototype.

In Rhino, the “FlowAlongSrf” function, RhinoNest, and ArchCut plugins were used together to create the geometries. Next, the “UnrollSrf” command with high tolerance was used to extract the geometry for machining the CFS. The labeling of parts was scripted and is based on material thickness, layer, and overall length.

### Foam

The choice to use rigid urethane foam for the mockups was dictated by both the retail availability of this product, and the relative dearth of competitive green alternatives in sizes below the 55-gallon drum. Both were two-part foams; the 1.5pcf was low-expansion strength from “Foam Power Inc.,” and the 3.0pcf foam was the “Smooth-On” brand. The most likely candidates to substitute are believed to be either icynene or soy-source urethane, both of which are commercially available.

### Materials

The full-scale mockups use four types of wood: 5/8” BC ply, 3/8” BC ply, most notably 3/8” bending Luan, and 1/4” Luan for the spacers inside the tubes. The bending Luan on interior and exterior faces is oriented so that its strong axis runs either perpendicular or *near* perpendicular to the length of the tube.



In this second of stage of physical prototyping, the different types of joinery and the assumptions made in chipboard were tested in the material from which they would presumably be cut.



Figure 14.1 | 4 Sections



Figure 14.2 | Beams A, B, C



Figure 14.3 | 4' Tube - Curved





Figure 14.4 | 8' Tube - Curving & Twisting



Figure 14.5 | Detail 1 - Section Distorts



Figure 14.6 | Detail 2 - Variable Joinery

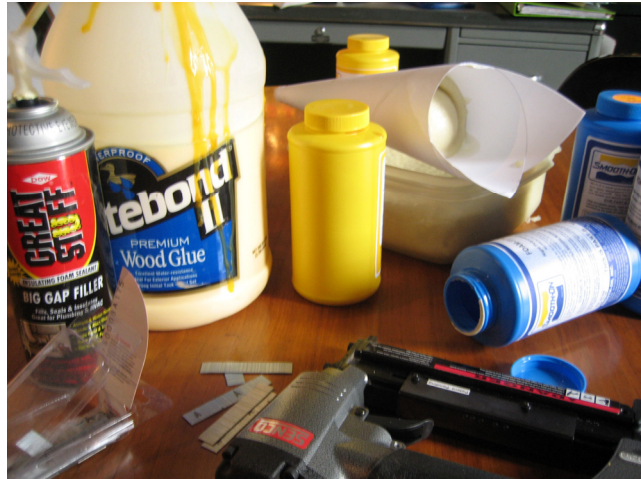


Figure 14.7 | All The Stuff



Figure 14.8 | Router Bits

## CHAPTER 15 | TRANSVERSE LOAD TESTS

### Testing - Round 1

The material thickness and joinery details of each section are shown in Figure 14.1. The lettering of each from the previous chapter corresponds to the Beam or Column letters that follow. Dr. Russell Gentry graciously ran the press despite overwhelming commitments on the Solar Decathlon house. The foam density, peak load, deflection, and observed failure cause of each section are located in Table 15.1.

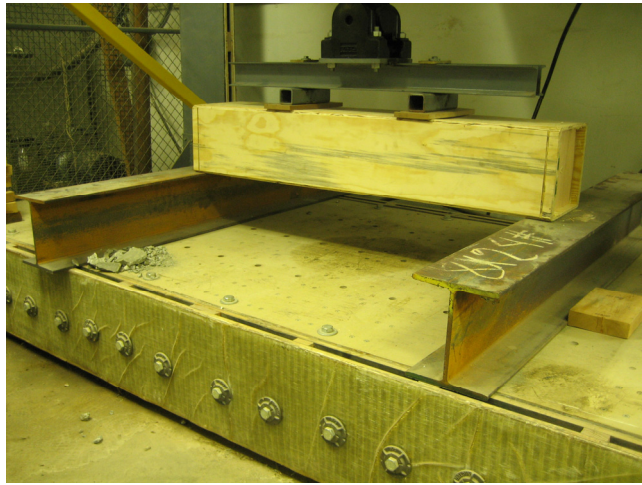


Figure 15.1 | Beam A - Before

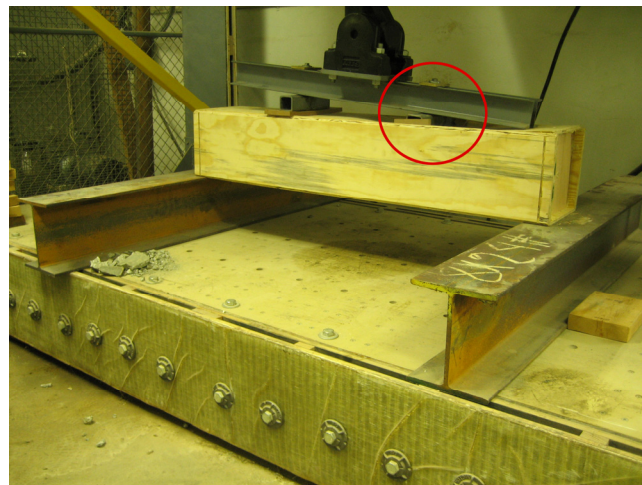


Figure 15.2 | Beam A - Local Shear Failure

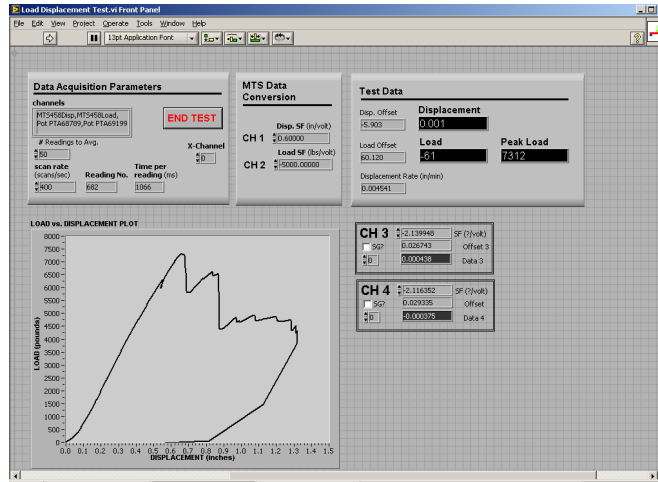


Figure 15.3 | Hydraulic Press GUI

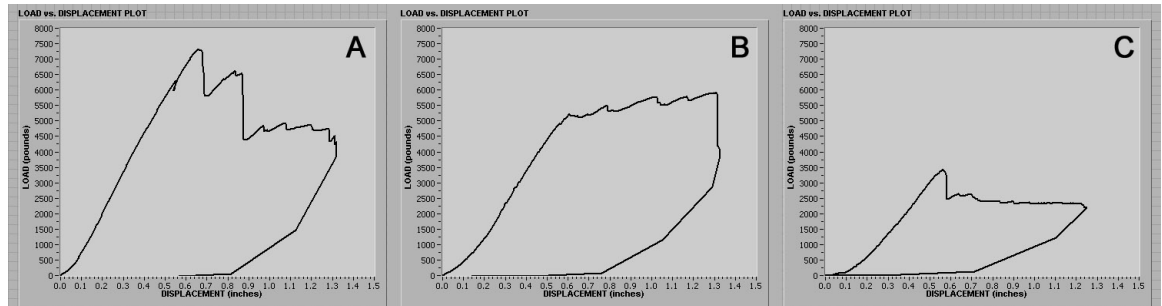


Figure 15.4 | Loading Diagrams - Peak then Plateau

Table 15.1 | Flexural Test Results

Beam	Filling	Peak Load	Failure Description	Deflection
A	3.0 pcf Foam, Solid	7312#	Local Shear @ Face	.01"
B	1.5 pcf Foam, 4" Hollow	5897#	Local Shear @ Face	.04"
C	1.5 pcf Foam, Solid	3426#	Improper Filling @ Joint	.138"





Figure 15.5 | Beam A - Failure Detail



Figure 15.6 | Beam B - Failure Detail



Figure 15.7 | Beam C - Failure Detail



Figure 15.8 | Beam B – Interior Detail (note chunk @ top)

Testing- Round 2

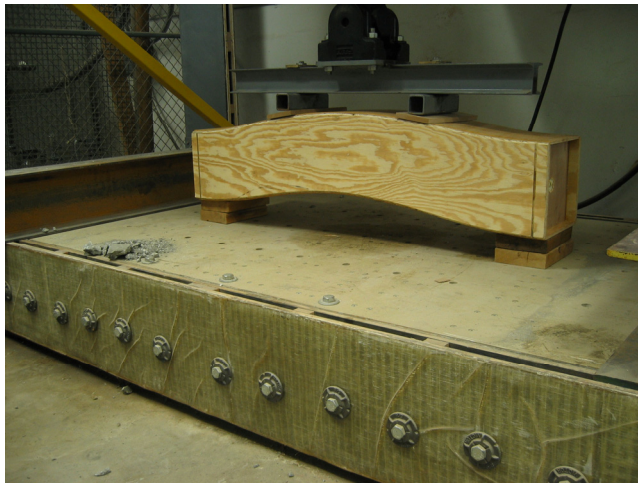


Figure 15.9 | Beam D - Curved Beam w/ Bending Plywood Faces

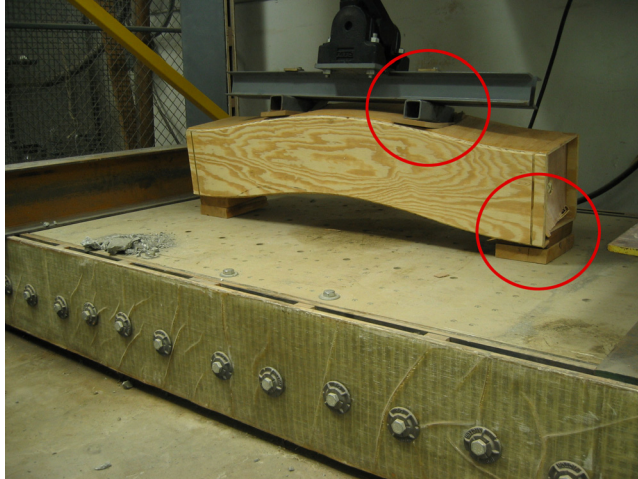


Figure 15.10 | Beam D @ Failure - Local Shear Failure

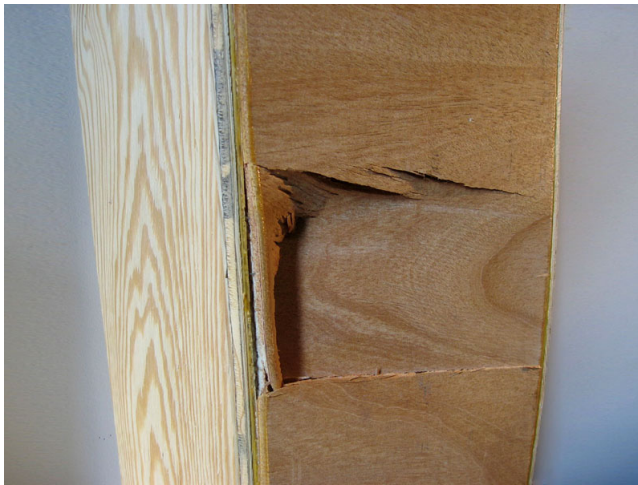


Figure 15.11 | Beam D - Failure Detail

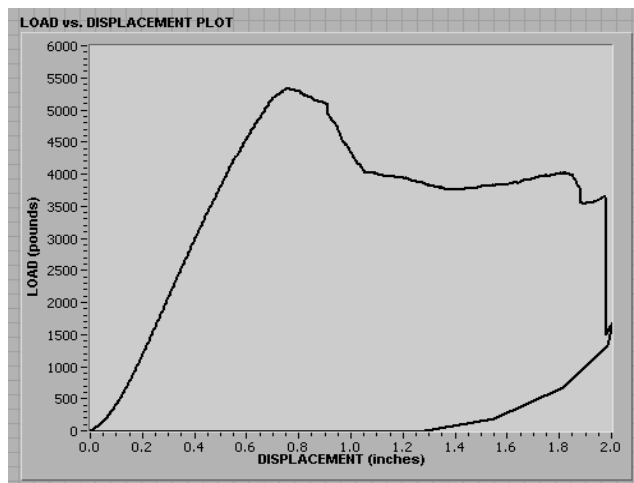


Figure 15.12 | Loading Diagram Beam D

## CHAPTER 16 | AXIAL LOAD TESTS



Figure 16.1 | Section D

Table 16.1 | Axial Test Results

Column	Filling	Peak Load	Failure + Location	Displacement
D	3.0 pcf Foam, Solid	30,000#	None	.001"

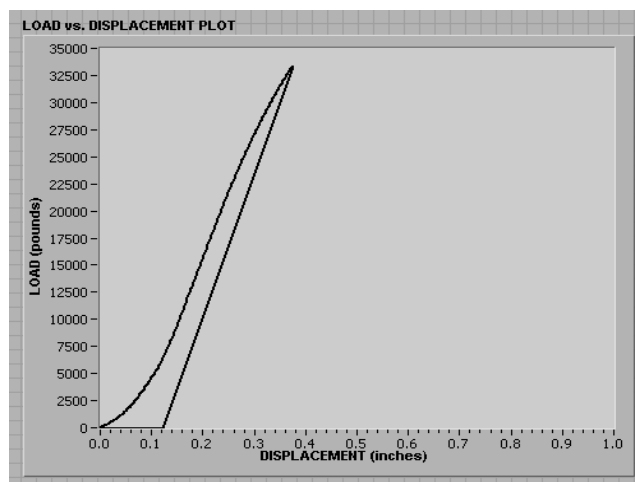


Figure 16.2 | Loading Diagram Section D





Figure 16.3 | Crushing @ 1" MDF Cap

Each practical test yielded something previously unknown about the performance of the system. In particular, the way the beams failed in the flexural test was generally favorable because the failure was not catastrophic as had been expected. Deflection was well within expected tolerances at (.01", .04", and .138" .001 respectively). The mode of failure was always local to the face of the exterior plywood and occurred around the feet of the loading fork. The force applied by the hydraulic press resulted in a staged failure that began with (1) local shear failure of the face and was followed by (2) crushing of the foam inside. In each case (even the improperly filled beam C), the section continued to perform at about two-thirds of its peak load after the initial failure. The horizontal portions seen in Figure 16.4 demonstrate this high post-failure performance, and suggest a safety factor with a ceiling at about two-thirds the peak load.

In general, this portion of the research is included not to represent the well-established structural validity of SIPS in general, but to support some of the specific assumptions being made in model and on paper. The 9"x9" section is the smallest dimension the tube half of the system would ever become, so that dimension was chosen as the condition to test.

## **PART FIVE- CONCLUSIONS**

## CHAPTER 17 | TYPE & METHODOLOGY

The attempts to create different types of variation in the exercises demonstrate the breadth of digital production methodology's impact, but also challenge strict typological thinking. Whether or not combining a shotgun with a split-level house is a desirable thing to do may remain debatable, but in any case, such hybrids still have yet to occur. This must be, at least in part, because the results would have been monstrous, if not untenable, with the techniques and technology of their day.

Ultimately, two worldviews are juxtaposed here; the relative-empiricist view, as represented by the research into typological exercises, and the Deleuzeian-realist view, as represented by the discussion of capacities and assemblage theory. In the first, we are looking down on collections of objects and their relationships; indexing, sorting, and cataloging their sordid properties. In the latter, we are peering up at mind-independent, property-and-capacity hierarchies to explain the impact of technology upon our architectural constructs. There are merits to both views, and flawed or not, taxonomic methodology is well suited to the task of establishing synthetic (or virtual) vocabularies that may serve as analogs for construction.

Assemblage theory is distinct from the taxonomic approach because it is able to provide causal explanations for variation that go unexplained in alternative modalities. The drawback to this is that it does not acknowledge the existence of essences whether absolute, relative, or otherwise. Even so, accepting the existence of one does not have to be, as Gombrich has taught us, like "the exclusion principle" that "denies the values it opposes."<sup>62</sup> While it is correct to observe that the essence of an object, especially a building, may be purely logical or virtual, it seems more

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<sup>62</sup> Gombrich, E.H.. Norm and Form. London: Phaidon Press, 1966, p. 97.

reasonable that this might be complement this with an acknowledgement of the structure and of the natural world which plays so completely into the act of making.

It is with this in mind that we return to marvel at the impact of digital production methodology. The fundamental technological improvement in the act of cutting, when coupled with the ability to pre-model everything virtually, adds up to an expansion in our capacity to produce. What we are experiencing are the repercussions of modeling and fabrication technologies that are radically more precise in not just two, but three dimensions. The potential for this singularity to affect the detached house by allowing unforeseen structural, formal, *even* typological variation is recognizably immense. As the formerly rigid seams of the built environment are now relaxed, it is now possible for architects to set their sights upon both type and typologies - instead of only the token.

The true object of the research, the component-based CFS system, is an initial attempt to use this new production methodology to reconsider one of the most fundamental systems of modern construction, light wood framing. In its current incarnation, the proposed CFS uses a layered modularity that allows it an alternate structural state and accommodates organic geometry more closely than the approaches of the past. The two most obvious drawbacks are assembly and the systems anisotropy, and for me, this will remain an open case.

In hindsight, there are things that certainly might be treated or done differently, and in a certain sense, exploration precedes selection in this work, so this is where the chase must end, for now. Because historically type has been constrained by the limited capacities of traditional production methodology, it does follow that a relative increase in these capacities now serves its liberation.

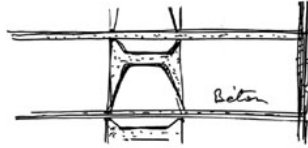
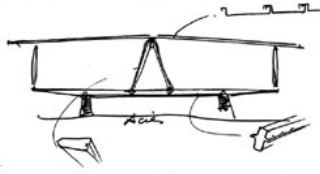
## APPENDIX

### Appendix A | Structure Typologies - Prouve

*Alphabet des structures*

*Alphabet der Systeme*

*Alphabet of Structures*



Type portiques axiaux  
Typ Mittelstütze  
Type of jointed frames

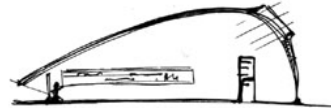
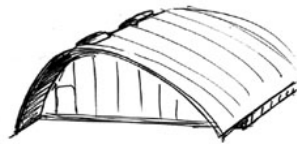


Type coque  
Typ Schale  
Shell type

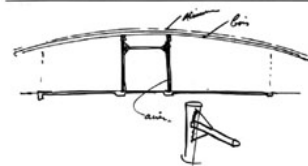
Type shed  
Typ Shed  
Shed type



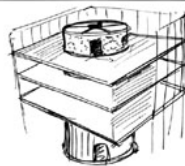
Type à béquilles  
Typ Krücke  
Propped type



Type voûtes  
Typ Tonne  
Vaulted type



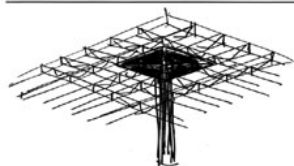
Type à portique axial en H  
Typ H-Stütze  
Type of H-shaped axial frame



Type à noyau central  
Typ mit tragendem Kern  
Centre core type



Type tabouret  
Typ «Tabouret»  
Stool type



Type réticulaire à surface  
Typ für freien Grundriß  
Variable area grid type



Type plastique  
Typ Kunststoff  
Plastic type

3 HOUSES where

FRAMING TYPOLOGY

&

PROGRAM "SCHEMA"

two "BLENDED"

to VARY

TYPE

3 HOUSES where

FRAMING TYPOLOGY

&

PROGRAM "SCHEMA"

two "BLENDED"

to VARY

TYPE



# DETACHED HOUSE TYPOLOGY

## 3 TYPES

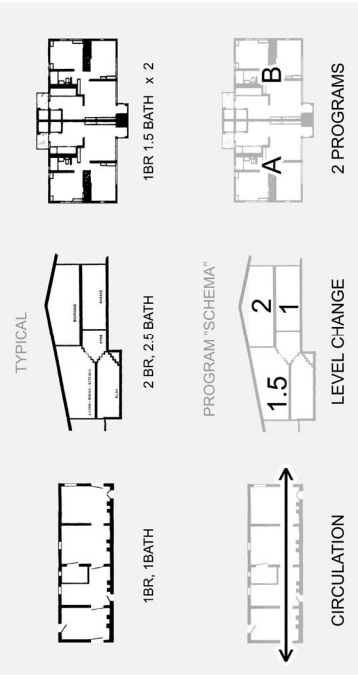
SHOTGUN



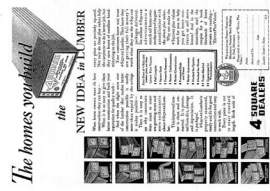
SPLIT-LEVEL



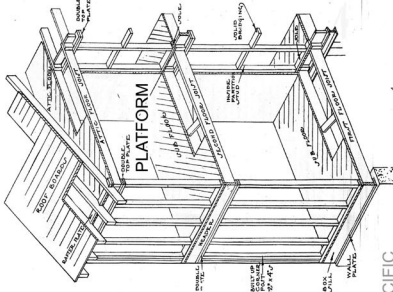
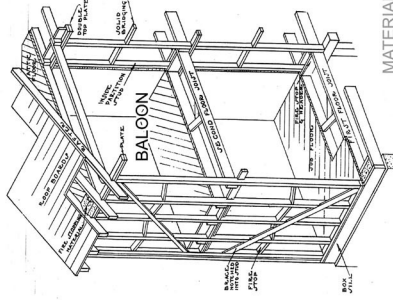
DUPLEX



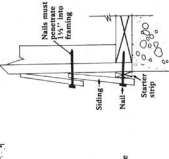
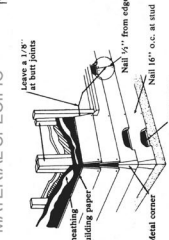
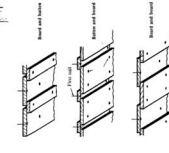
## MATERIALS & METHODS



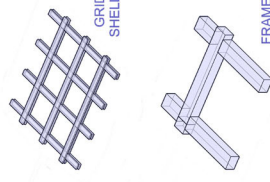
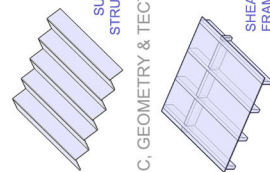
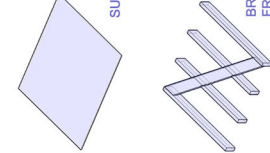
## FRAMING SYSTEMS



## MATERIAL SPECIFIC



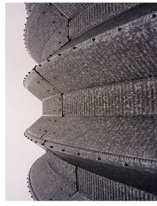
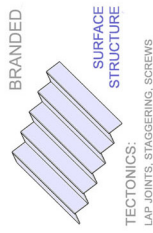
## STRUCTURE CLASS





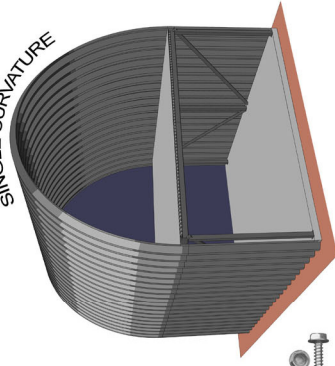
# FRAMING SYSTEMS & TYPE

## QUONSET FRAMING

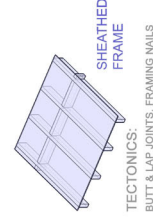


STAMPED METAL STRIPS

SINGLE CURVATURE

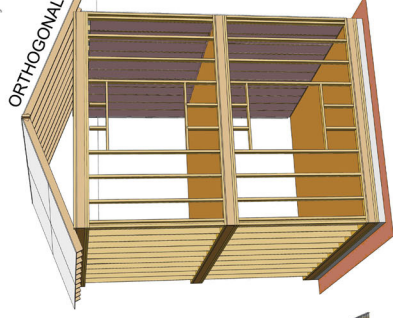


## PLATFORM FRAMING

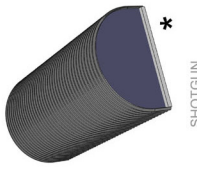


WOOD

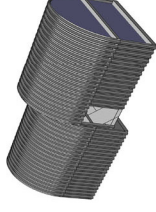
Turnstijl.com  
M.Arch 1 - May 2007



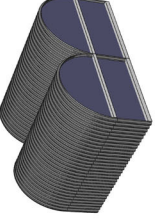
## QUONSET FRAMING : ATTEMPTING 3 TYPES



SHOTGUN

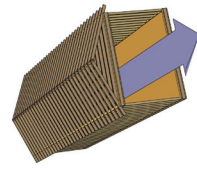


SPLIT-LEVEL

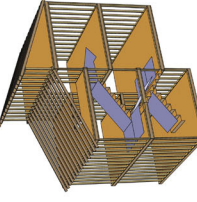


DUPLEX

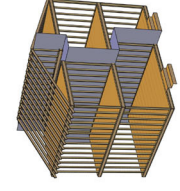
## PLATFORM FRAMING : 3 TYPES



SHOTGUN

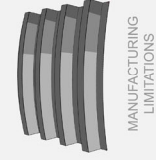


SPLIT LEVEL

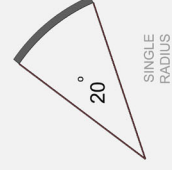


DUPLEX

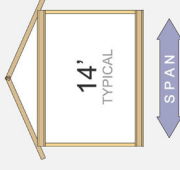
## CAPACITIES & CONSTRAINTS



MANUFACTURING LIMITATIONS



SINGLE RADIUS



14' TYPICAL

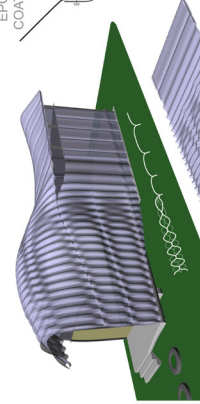


4'x8'

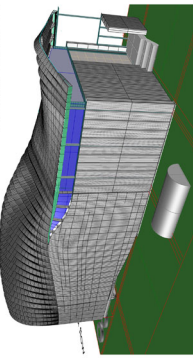
SPACE DIVISION

GOOD SPAN DISTANCE. POOR AT DIRECTION CHANGE & INSULATION POOR SPAN DISTANCE & FORM GOOD AT DIRECTION CHANGE

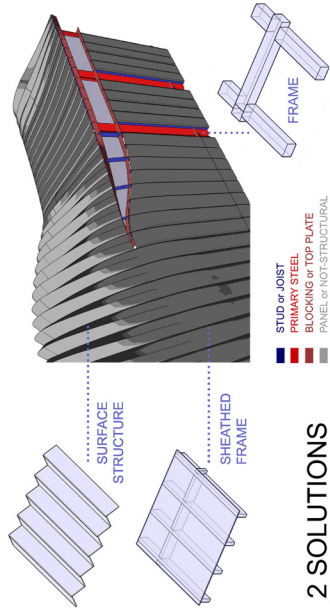
# AN ALUMINUM, HYBRID-FRAMED, LEVEL-CHANGING



A 3D architectural rendering of a building facade. The main structure is a tall, rectangular volume with a grid-like texture, possibly representing a curtain wall or a facade of panels. To the left, a curved, ribbed section of the building is visible. Above the main volume, there are smaller, more complex structures, including what looks like a staircase or a series of terraces. The entire scene is set against a dark, textured background, and a small, light-colored cylindrical object is visible in the lower right foreground.



STUD or JOIST  
PRIMARY STEEL  
BLOCKING or TOP PLATE  
PANEL or NOT-STRUCTURAL



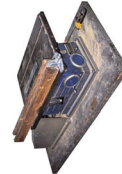
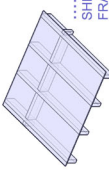
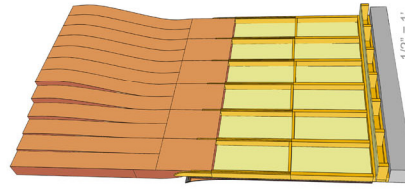
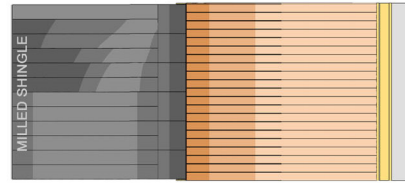
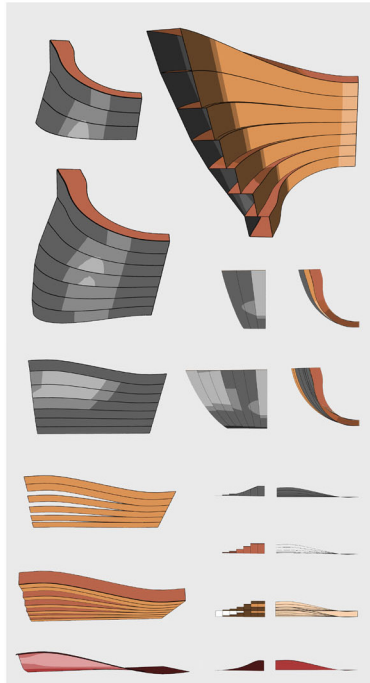
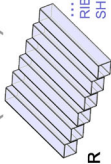
FRAME SHEATHED

# CANNOLI FRAMING SYSTEM (CFS)

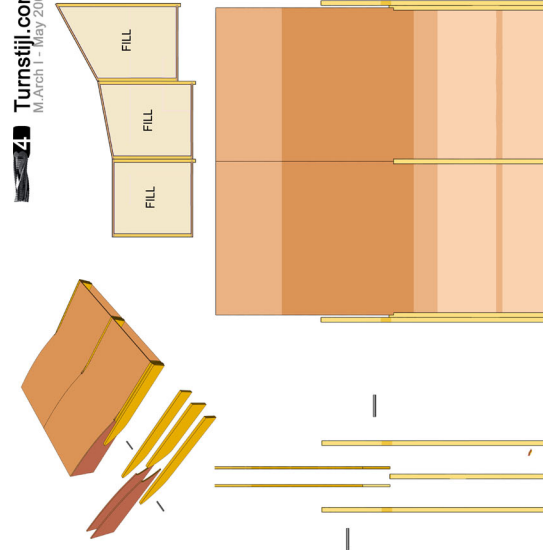
PEOPLE WANT WOOD HOUSES!

LESS MATERIAL OVERALL - COMPOUND CURVATURE

LESS METAL FASTENERS - OFF-SITE - NO CONTRACTOR



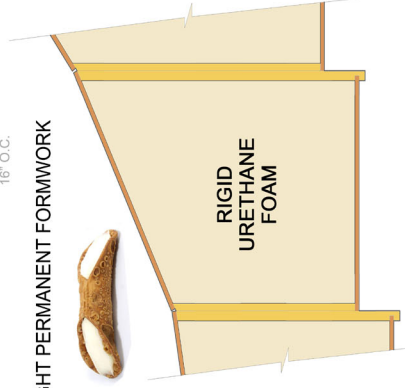
Turnstijl.com  
March 1 - May 2007



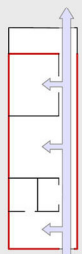

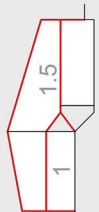


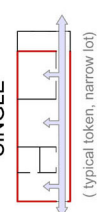
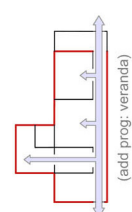
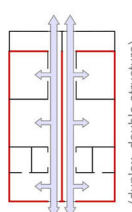
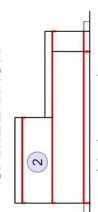
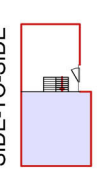
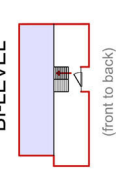
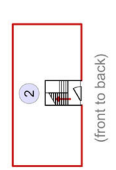
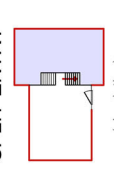


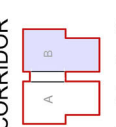
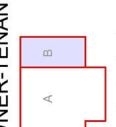
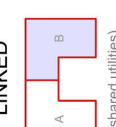
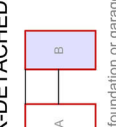
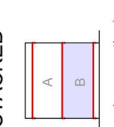
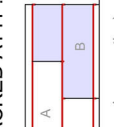
16" O.C.  
LIGHTWEIGHT PERMANENT FORMWORK



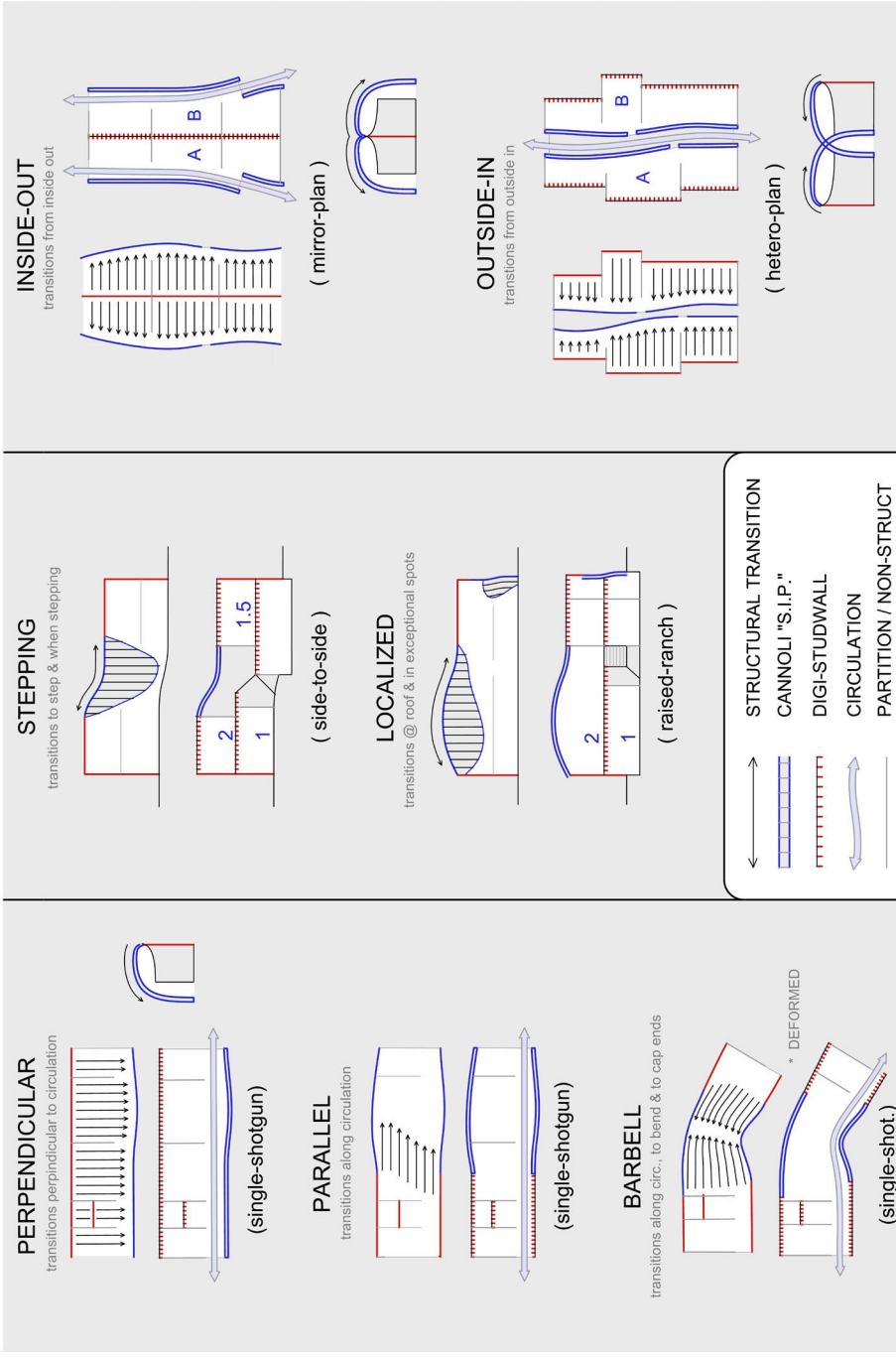
ADHESIVES



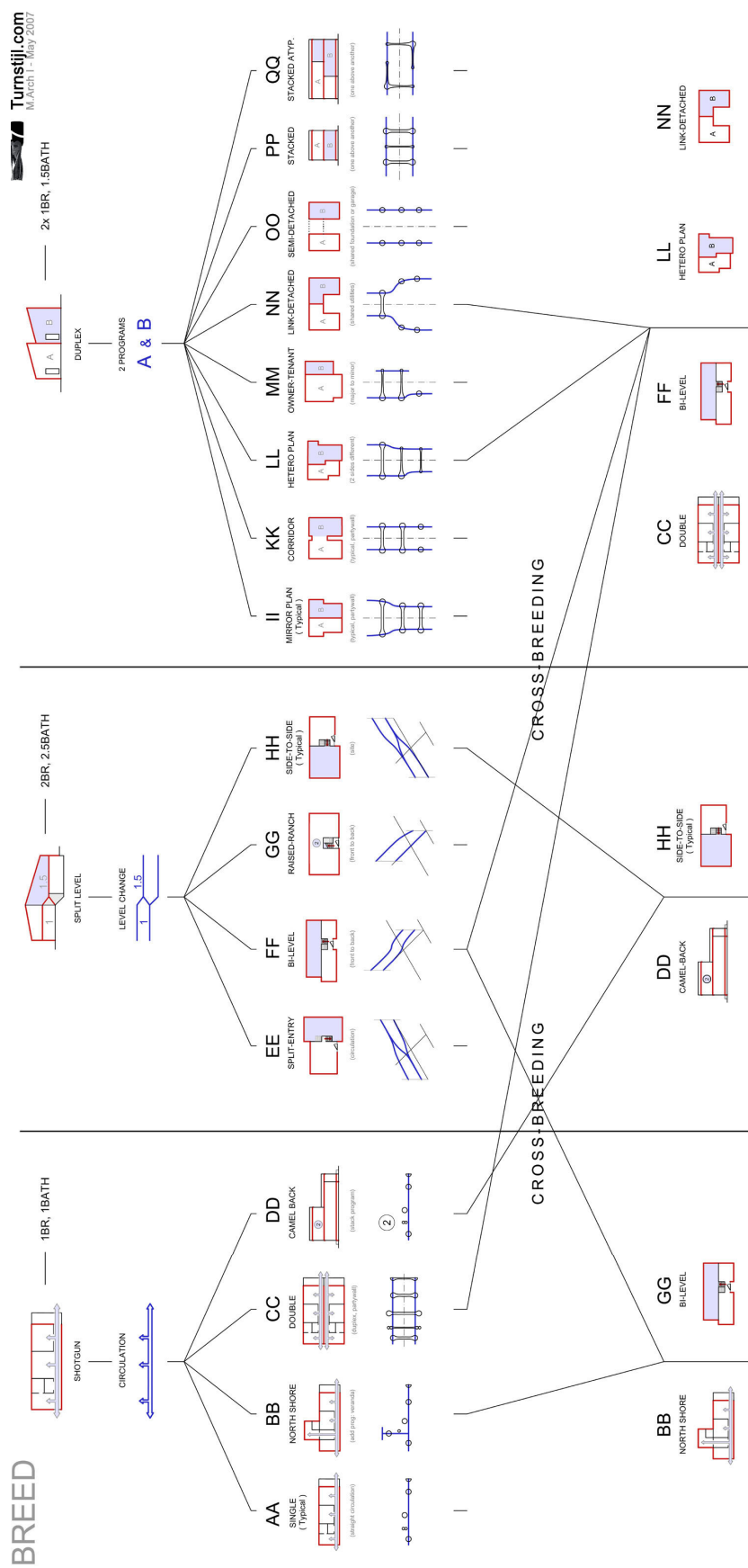
# TYPE & SUB-TYPE

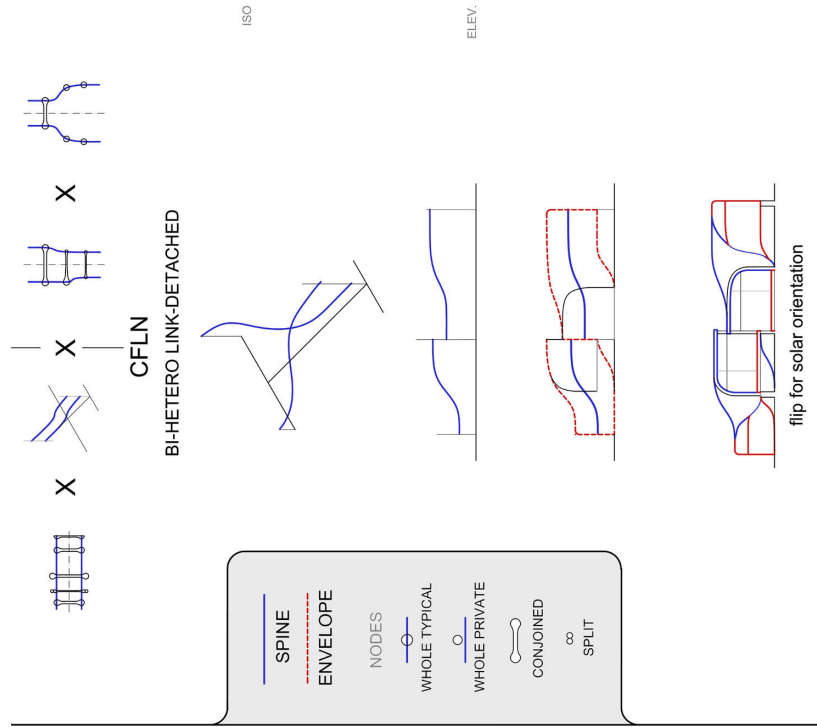
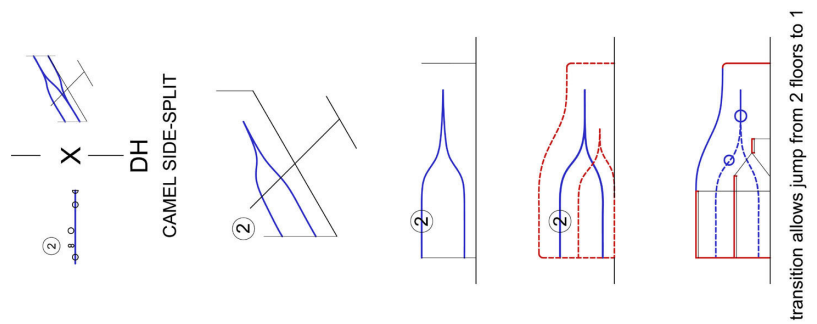
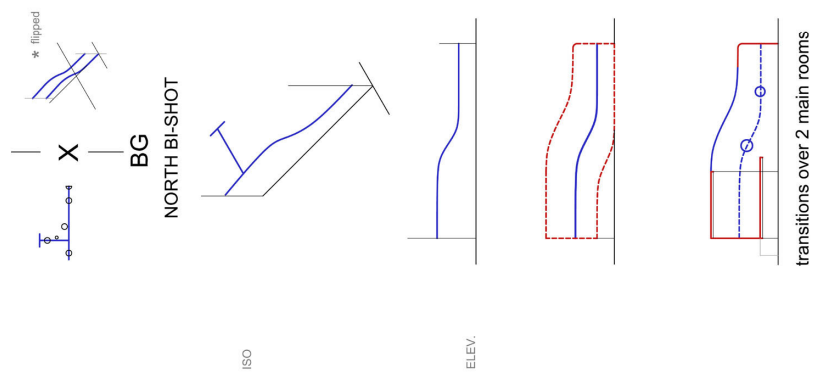
<p><b>SHOTGUN</b></p>  <p><b>CIRCULATION</b></p>  <p><b>1BR, 1BATH</b></p>	<p><b>SPLIT LEVEL</b></p>  <p><b>LEVEL CHANGE</b></p>  <p><b>2BR, 2.5BATH</b></p>	<p><b>DUPLEX</b></p>  <p><b>2 PROGRAMS</b></p> <p><b>A &amp; B</b></p> <p><b>1BR, 1.5BATH x 2</b></p>
<p><b>SINGLE</b></p>  <p>( typical token, narrow lot )</p> <p><b>NORTH SHORE</b></p>  <p>(add prog. veranda)</p> <p><b>DOUBLE</b></p>  <p>(duplex, double structure)</p> <p><b>CAMEL BACK</b></p>  <p>(stack program)</p>	<p><b>SIDE-TO-SIDE</b></p>  <p>( typical token, irreg. site )</p> <p><b>BI-LEVEL</b></p>  <p>(front to back)</p> <p><b>RAISED-RANCH</b></p>  <p>(front to back)</p> <p><b>SPLIT-ENTRY</b></p>  <p>(circulation)</p>	<p><b>MIRROR PLAN</b></p>  <p>(partywall, common-attic)</p> <p><b>HETERO PLAN</b></p>  <p>(2 sides different)</p> <p><b>CORRIDOR</b></p>  <p>(partial partywall)</p> <p><b>OWNER-TENANT</b></p>  <p>(major to minor)</p> <p><b>LINKED</b></p>  <p>(shared utilities)</p> <p><b>LINK-DETACHED</b></p>  <p>(shared foundation or garage)</p> <p><b>STACKED</b></p>  <p>(one above another)</p> <p><b>STACKED ATYP.</b></p>  <p>(one above another)</p>

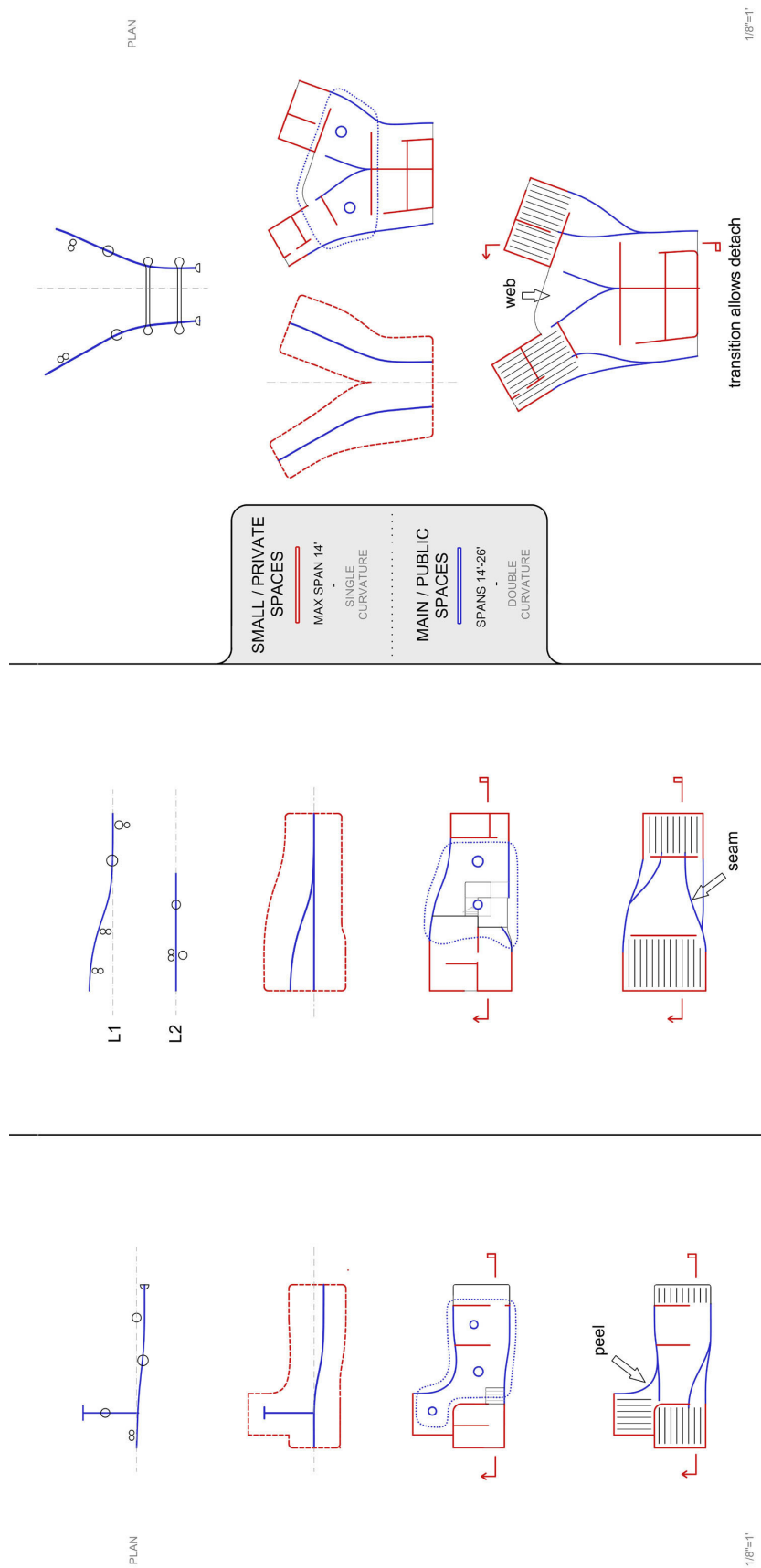
# TYPE ATTRACTS TRANSITION









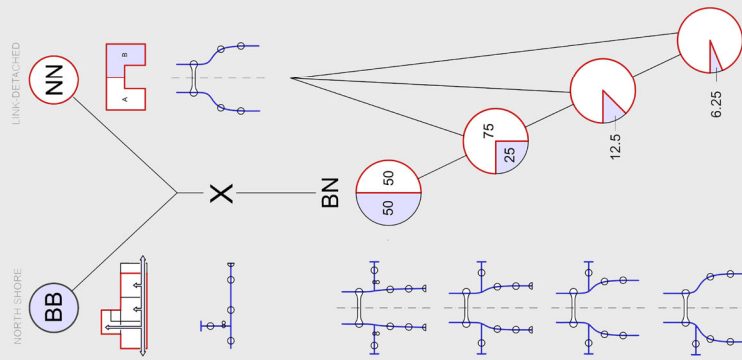




# PERSONALIZE BREED + DETAIL

STEPS

1. CHOOSE PROGRAM QUANTITY
2. DEFINE TRANSITION
3. CROSS-BREED TYPE



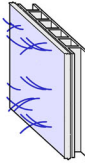
ROOF

ROOFING

- o BUILT UP ROOF (B.U.R)



- o GREEN ROOF



- o METAL ROOFING



ACCESSORIES (3 free)

ASSORTED EXTRAS

- o PV ARRAY
- o DECK
- o PORCH
- o DOGHOUSE
- o MAILBOX
- o TREEHOUSE
- o GATE / DOGFENCE
- o OUTHOUSE / SHED
- o ELABORATE GRILL
- o CARPORT
- o ABOVE GROUND POOL/SPA
- o TRAMPOLINE

TWEAKS & ADJUSTMENT

PCT. (%) DOUBLY CURVED

- o NONE
- o 25%
- o 50%
- o 75%
- o ALL

TRANSITION RATE

- o 1.0x
- o 1.25x
- o 1.5x
- o 2.0x
- o 3.0x

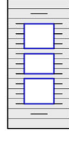
GEOMETRY BEHAVIOR

- o TIGHT
- o NORMAL (given)
- o LOOSE

( See SYSTEM GEOMETRY )

WINDOWS

- o INTERRUPT (scale, then interrupt)



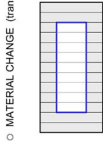
- o CUT PROFILE (2D)



- o TWIST (3D - twist or grill)

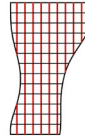


- o MATERIAL CHANGE (translucent panel)

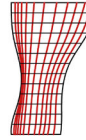


SYSTEM GEOM

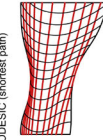
- o STRAIGHT (plan geom generates)



- o CV GENERATED (aligns, norm to srf)



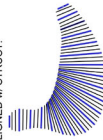
- o GEODESIC (shortest path)



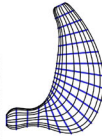
CLADDING

CLADDING GEOM

- o ALIGNED w/ STRUCT.



- o NOT-ALIGNED w/ EITHER



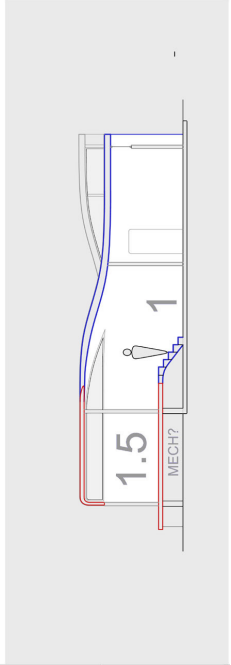
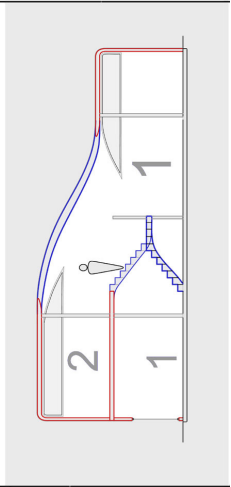
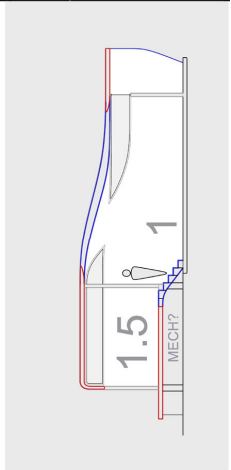
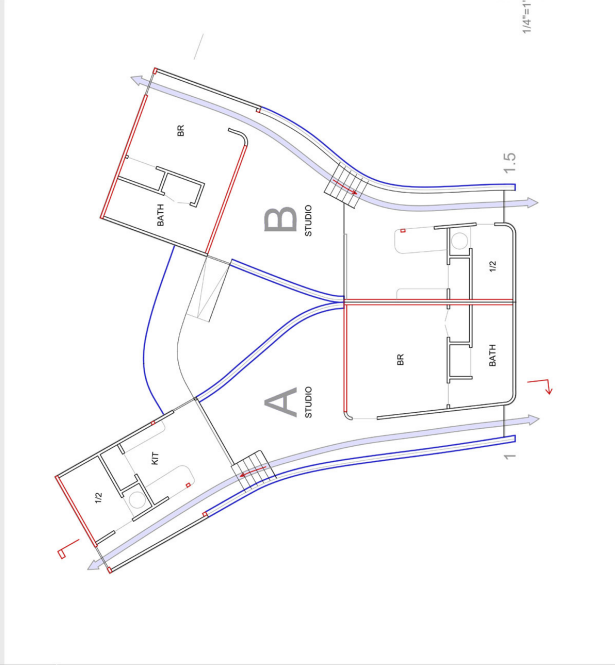
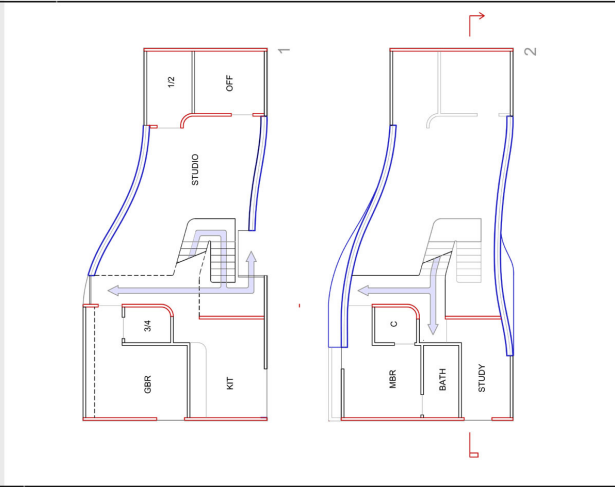
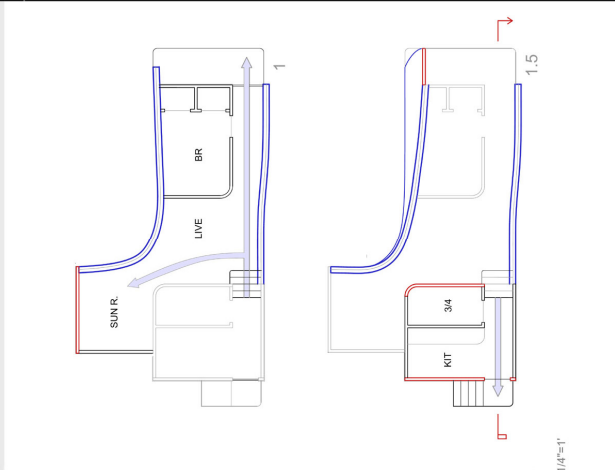
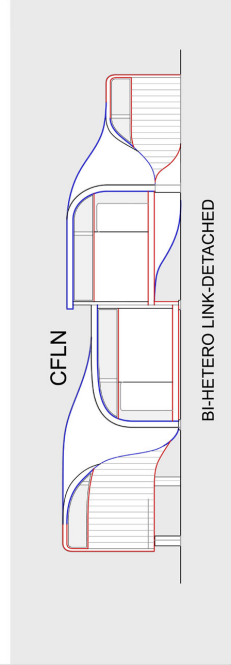
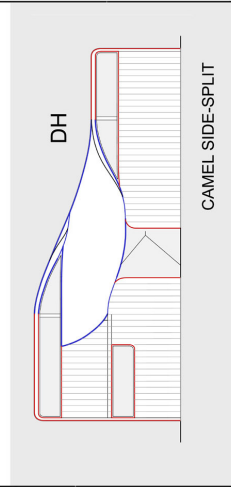
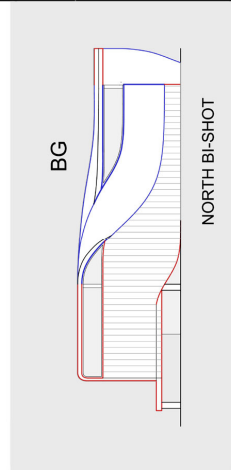
WOOD

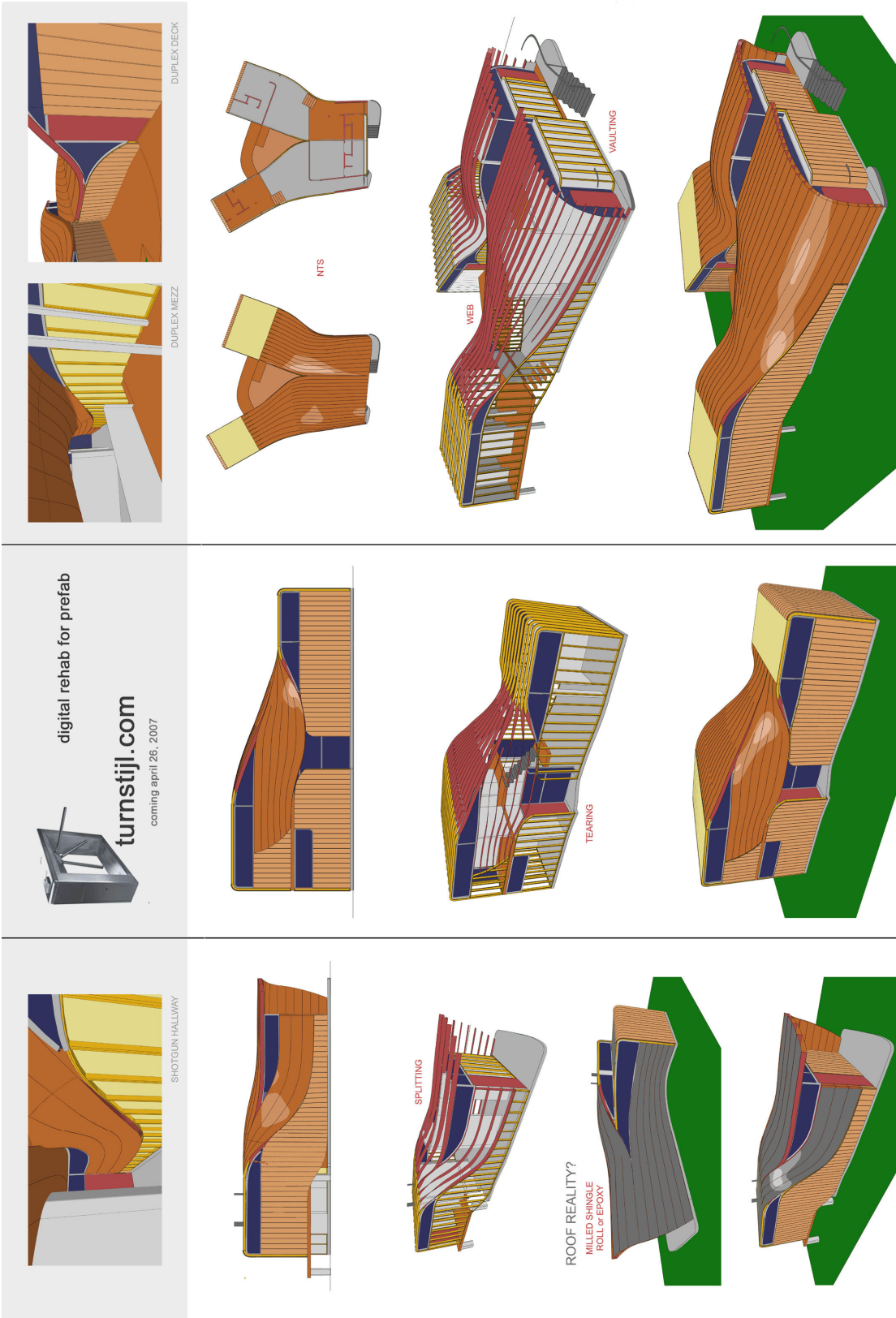
- o SHUPLAP
- o TONGUE & GROOVE
- o BOARD & BATTON
- o BOARD & BOARD
- o SHINGLE / TILE

METAL

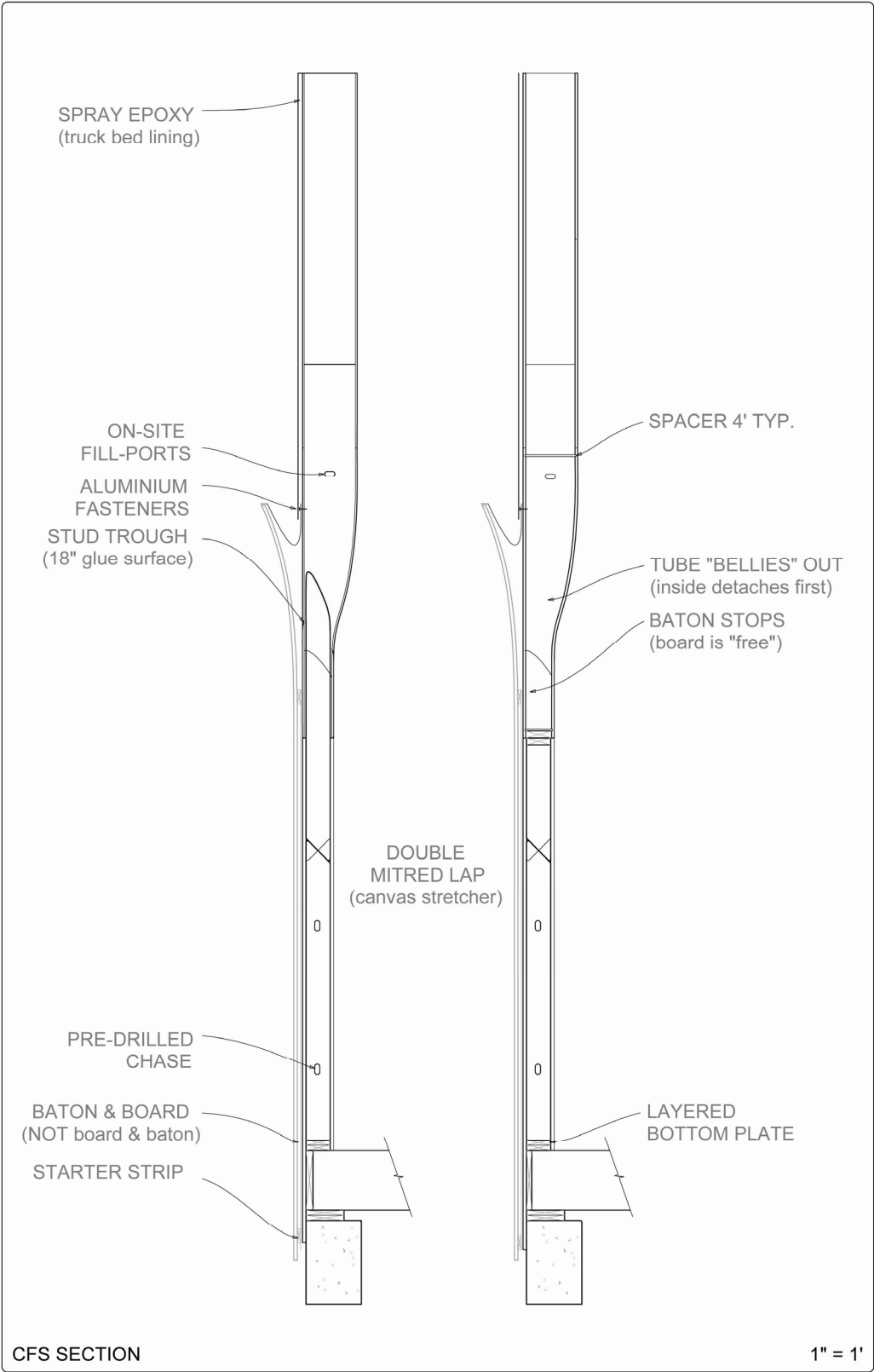
- o STANDING SEAM
- o BATTON SEAM
- o METAL PANELS

# FINAL PLANS

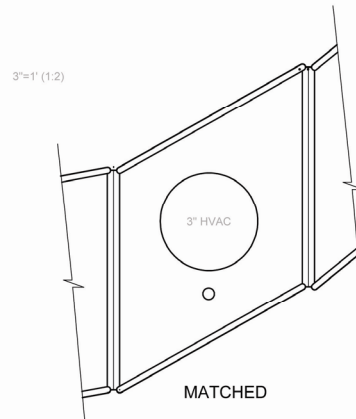
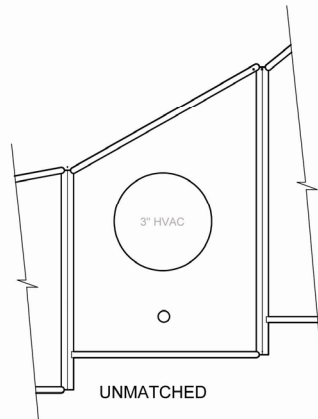




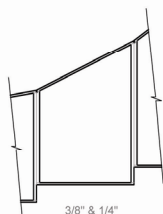
Appendix C | The CFS Gen1



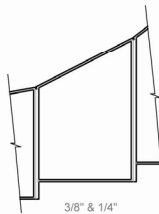




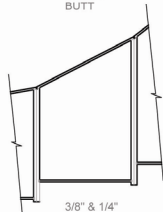
#### INITIAL SPECULATION



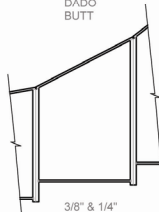
3/8" & 1/4"  
V MITRE  
BUTT



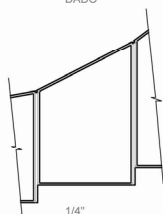
3/8" & 1/4"  
V MITRE  
DADO  
BUTT



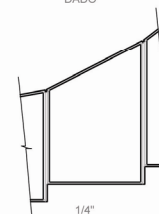
3/8" & 1/4"  
V MITRE  
DADO



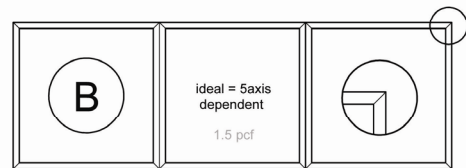
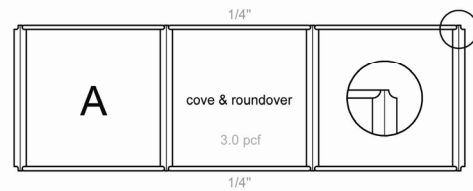
3/8" & 1/4"  
V MITRE  
DADO



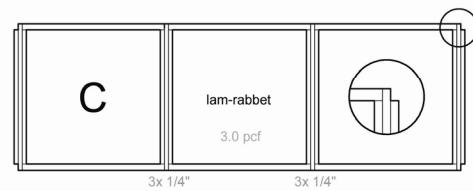
1/4"  
V MITRE  
BUTT  
(ALTERNATE)



1/4"  
V MITRE  
BUTT  
(ALTERNATE)



materials 3/8" unless otherwise spec.



#### CFS DETAIL STUDIES

## 5.6 Modularity Types

The PDM Group (Tiihonen et al., paper, 1995) used five categories of components, in a scale close to a salesperson's perspective; dependencies between components are kept as simple and standardized as possible:

1. *standard* components (one size, one design)
2. *modifiable* standard components (the component itself can easily be reconfigured to fit a customer, typically in software and electronics)
3. *parameterized* components (size and design parameters stated per order, before delivery<sup>14</sup>)
4. components *designed per category* of customers (typical for physical interfaces to a product's environment)
5. *promise-ware* components – not yet designed, requiring new specification and design work (quite typical of software or high-tech components and of businesses with an “Engineer-to-order” tradition).

In an optimal component strategy, we stress the desirability of PDMG's category 1, 2, 3 above, trying at the same time to keep 4 at a reasonable level and to minimize 5.

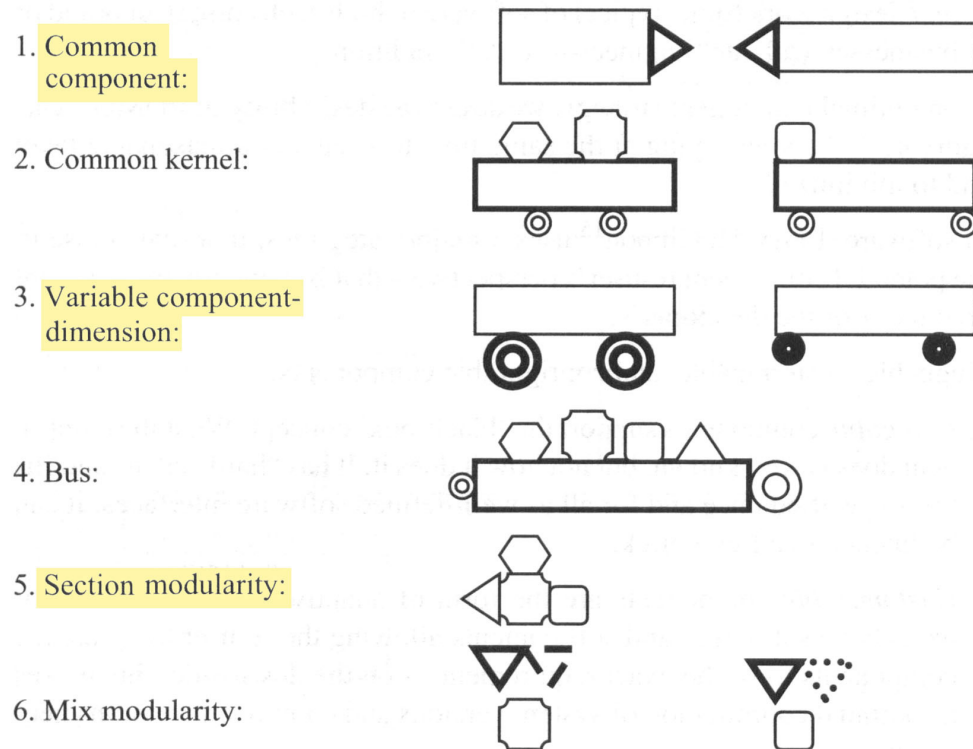
In software, Barry McGibbon<sup>15</sup> uses 3 major categories, in a scale close to the potential component re-user's perspective – that is, typically the software architect's or the developer's:

pluggable, customizable, and configurable components.

1. *Pluggable* components support the ‘black-box’ concept. What the component does is well known, but not how it does it. It has “hard” edges and fittings specified once and for all as well-defined software interfaces; it can be likened to a Lego brick.
2. *Customizable* components are the form of adaptive reuse. The components have soft edges and soft contents allowing the re-user to adjust the components to fit the exact requirements – on the down-side, this makes a continual coordination of system versions and component versions necessary.
3. *Configurable* components are pluggable components that can have their behavior or data changed through *well-defined mechanisms*. These still remain a ‘black box’ as the configurator does not know how the internals of the component have been changed, it only knows the expected *effect* of the change<sup>16</sup>.



Ulrich & Tung once defined a scale of five component-architecture categories, or kinds of modularity, closer to a production or manufacturing perspective. A sixth category was added by B. J. Pine and called mix modularity (Pine, 1993). Some of their categories overlap since the classification was based on the components' way of complementing each other (figure 5-3).



**Figure 5-3:** Modularity categories inspired by production<sup>17</sup>.

1. *a common component* – the same component type employed in several products (now typical of automotive & manufacturing, electronics & computers, and many other industries)
2. *a common kernel* – a basis combined with various components in various products (like the fore-mentioned VW-platform A2 in Skoda Octavia, Audi A3 and Golf/Rabbit/Bora 4)
3. *variable component-dimension* in various products (similar to PDMG's parametrized components above)

<sup>17</sup> B. J. Pine's, complemented version (Pine, 1993).



4. *bus* – a common standard basis, easily connected to any other component types supporting its standard interfaces (today typical of PCs or of automotive electronics or of large configurable software environments, for instance IBM ®Websphere’s Eclipse engine)
5. *section modularity*, like Lego-bricks – an architecture interconnecting any component with any others, in an ever-growing number of combinations. This requires hard homework in design (and most often an industry standard) but it pays off in terms of maximum robustness, i.e. resilience to heterogeneous or volatile requirements. Here, the trick is the versatile standardized interface between components, which fits in, whatever the component's shape, functionality or inside – like in Lego, or railway carriages in most of Europe, or the TCP/IP communication protocol (figuratively, the standard “plumbing software” under the Internet).
6. *mix modularity*, easily combined with the other five points (for example in paint/finish/coating, raw material blends, additives).

With a consistent cross-product or cross-brand co-modularization, there is of course a risk of some market segments perceiving products from very different price-categories as *too similar*. In B2B, this is seldom a big issue; obviously, the costs and long-term benefits of a truck (i.e. lorry) are analyzed much more thoroughly by customers than its looks; this customer attitude is more common in B2B.

With consumers however (B2C), similarity is a real issue in many industries: why buy an Audi instead of two Škodas<sup>18</sup>, or why go to an expensive high-profile bank, instead of a website providing exactly the same service package at a fraction of the price (and sometimes, even co-owned by the very same bank), or why pay an SAS airline ticket instead of three Snowflakes (the same owner, and same planes, but two brands until recently)? Parameterized or modifiable components, or those designed specifically for a product category, are often superficial and are placed on the surface in order to distinguish the look-and-feel between brands.

Carmakers Ford and Jaguar are a good example of how components can be shared successfully “under the bonnet”, yet still dramatically differentiating the mid-market Ford Mondeo from the executive-saloon Jaguar “X”.

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